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A SIMULATION STUDY OF THE FORCE MIX PROBLEM IN CLOSE AIR SUPPORT OPERATIONS

Dennis K. Leedom, et al

Air Force Institute of Technology

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13. ABSTRACT

A computer program was designed and constructed which simulated the operation of a single combat aircraft squadron in a close air support situation. The simulation model was specifically designed to highlight differences in effectiveness, vulnerability, availability, and cost between two aircraft with two different degrees of avionics sophistication. A weather model included in the simulation was based upon an analysis of long-term climatological records compiled from hourly weather observations at Bitburg Air Base, Germany.

A hypothetical example was used to demonstrate the utility of the simulation model. Specifically, two different types of aircraft were postulated and used in the close air support squadron. Results of this example showed that the increased costs of advanced avionic equipment can be justified on an attrition cost per target killed basis. Furthermore, the use of a mixed aircraft squadron was shown to result in higher target kill rates under certain conditions. Weather conditions were shown to have a significant effect on squadron performance with attrition costs rising during bad weather conditions.

An analysis of the simulation model along with the results of the hypothetical example led to the conclusion that the model could serve as a useful tool for studying the close air support problem. Specific areas capable of being addressed by the simulation model are (1) force-mix studies, (2) avionic equipment tradeoff studies, and (3) sensitivity studies examining particular portions of the close air support operation. Finally, the Markovian model developed from historical weather data provided a good representation of the weather throughout the simulation experiments.

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IN CLOSE AIR SUPPORT OPERATIONS

THESIS

GSA/SM/73-11

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and
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Captain USAF

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THESIS

Presented to the Faculty of the School of Engineering

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Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

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Preface

This paper describes an attempt to design, construct, and test a computer model which simulates the operation of a single close air support squadron. This investigation focused primarily upon highlighting differences in effectiveness, vulnerability, availability, and cost between aircraft with two different degrees of avionics sophistication. In addition, the effects of weather state changes on the operation of the squadron were explored.

We wish to thank our advisor, Major Jon Hobbs of the Systems Management Department, for his valuable comments and guidance throughout this period of research. We are also indebted to Captain Robert Tripp of the Systems Management Department for his helpful suggestions regarding the simulation techniques used in this study.

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Dennis K. Leedom
Arnold R. Thomas

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Abstract

Along with the complexity and increased effectiveness of today's modern fighter-bomber aircraft, have come increased procurement and operating costs. These costs have risen to the point where Air Force decision-makers have begun to ask whether or not the increased effectiveness of advanced avionic systems and weapon delivery systems are worth the increased costs. In addition, is it advantageous to permit a mixture of sophisticated and unsophisticated attack aircraft to be used within a single combat squadron?

To answer these questions, a computer program was designed and constructed which simulated the operation of a single combat aircraft squadron in a close air support situation. The simulation model was specifically designed to highlight differences in effectiveness, vulnerability, availability, and cost between two aircraft with two different degrees of avionics sophistication. In addition, the simulation employed a Markovian weather model to provide hourly weather changes. The weather model was based upon an analysis of long-term climatological records compiled from hourly weather observations at Bitburg Air Base, Germany.

A hypothetical example was used to demonstrate the utility of the simulation model. Specifically, two different types of aircraft were postulated and used in the close air support squadron. A basic type of aircraft was considered to have only the avionic equipment necessary to perform the basic close air support mission. An advanced aircraft was considered to have a stand-off weapon delivery capability and an increased ECM capability. Results of this example showed that the increased costs of advanced avionic equipment can be justified on an attrition cost per target killed basis. Furthermore, the use of a mixed aircraft squadron

was shown to result in higher target kill rates under certain conditions. Weather conditions were shown to have a significant effect on squadron performance with attrition costs rising during bad weather conditions.

Further parametric studies with this example revealed that sortie scheduling restrictions can influence the average attrition cost per target killed for a range of different aircraft mixtures within the squadron. Finally, the simulation model demonstrated the potential cost savings related to area defense suppression, target defense suppression, and improvement of ordnance effectiveness.

An analysis of the simulation model along with the results of the hypothetical example led to the conclusion that the model could serve as a useful tool for studying the close air support problem. Specific areas capable of being addressed by the simulation model are (1) force-mix studies, (2) avionic equipment tradeoff studies, and (3) sensitivity studies examining particular portions of the close air support operation. Finally, the Markovian model developed from historical weather data provided a good representation of the weather throughout the simulation experiments.

A SIMULATION STUDY OF THE FORCE MIX PROBLEM IN CLOSE AIR SUPPORT OPERATIONS

I. INTRODUCTION

The Problem

Like most weapons systems in the arsenal of the United States Air Force, modern fighter-bomber aircraft have undergone a complete transformation in the last three decades. The simple attack fighters of World War II and the Korean War have been replaced by aircraft that are vehicles for highly complex electronic systems, systems designed to increase the effectiveness and safety of the fighter-bomber mission. Generally, these systems have permitted more accurate weapons delivery at greater release distances from the target with more electronic protection from enemy defenses. Predictably, with this increase in capability has come a corresponding, but not always proportional, increase in the costs associated with procuring and operating the sophisticated new avionics systems.

A Rand study of the effectiveness of acquisition procedures for major weapons systems (Ref 37) established that, of the two principle unknowns in the acquisition process, cost and performance, performance exceeds specifications as often as it falls short. Cost usually overruns. This implies that contractors attempt to meet or exceed performance specifications at the expense of time and money. A weapon system's performance specifications reflect the total environmental conditions that are projected to be that system's future operational milieu. (Ref 37:1) In the case of fighter-bomber aircraft, target characteristics certainly have a major effect on weapon system design, but other operational considerations are the enemy's defense environment and the

natural environment. The essentials of the natural environment for fighter aircraft include the terrain, day versus night, and the weather conditions. Although Huschke in his work at Rand addressed only the weather aspect (Ref 37:1), the other factors -- targets and defenses -- impose problems whose solutions rely on consideration of the entire operating environment. For example, if enemy defenses deny a close approach to the target, the required standoff weapon may have characteristics that prohibit its use under conditions of poor target visibility. When weather conditions permit employment of a standoff weapon, the target may be one that requires close visual identification by the aircraft pilot.

Huschke says, "Targets that are difficult to acquire, and defenses and weather conditions that add to that difficulty, force an increasing demand for complex avionics: to the old requirement for an 'all-weather' capability is added a requirement for a 'standoff' capability." (Ref 37:1) Besides being expensive to procure, complex avionics mean added problems: cost and schedule overruns, reduction in total system reliability, and greatly increased maintenance problems. Therefore, a sophisticated system is a mixed blessing, and the operational value of increased performance must be balanced against appreciable direct and indirect penalties. (Ref 37:2) One way of striking this balance would be to employ a mixed force of complex and simple (avionically simple) aircraft in a combat theater or unit.

The intent of this thesis is to show that if a combat fighter-bomber squadron is to be supplied a single type of basic aircraft configured in varying degrees of avionics sophistication, analysis can be used to estimate the appropriate mix of these aircraft to be

assigned. In addition, one approach to answering this force-mix question will be demonstrated.

Objectives of Research

The objectives of the research were:

(1) To develop a computer simulation model of a close air support engagement, with particular emphasis on highlighting the differences in effectiveness, vulnerability, availability, and cost between aircraft with two different degrees of avionics sophistication.

(2) To use the model to study possible approaches to the problem of selecting an optimum mix of the two types of aircraft.

(3) To demonstrate how sensitivity analyses of the variables included in the model can be used to study certain aspects of the force-mix problem.

(4) To suggest possible extensions and uses of the model.

Background

The concept of a mixed force of aircraft designed for different missions is certainly not unique. Perhaps the best example of this idea can be found aboard Navy attack aircraft carriers where the complement of aircraft include interceptors for fleet defense, reconnaissance aircraft, tankers for airborne refueling, helicopters for rescue, utility aircraft, and the attack squadrons for the ground-attack mission. The attack squadrons are further specialized into different types of aircraft and may range from the highly complex, all-weather A-6 intruders to the simpler, but highly effective, A-7 Corsair IIs to the very basic A-4 Skyhawks. Each attack aircraft is more or less designed for a specific mission which is defined by weather conditions,

target types, enemy defenses, night versus day, range to the target, and a host of other operational considerations. Theoretically, this specialized aircraft can perform a specific mission more efficiently than another aircraft, which may be under-equipped or over-equipped to handle the job.

A natural extension of this idea is to use a single basic airframe, such as the F-4 or F-111, and through the addition of various avionics packages, configure it to meet different mission requirements. There is little operational history of this type of force-mix being employed. Although there are various models of some aircraft, such as the F-4C, F-4D, F-4E, and the RF-4C, their differences are more than can be brought about by the mere addition or subtraction of avionics packages, and they are rarely combined to form a nonhomogeneous fighting unit like a squadron or wing. For example, the F-4E has an entirely different airframe and engines than the F-4C and the F-4D. Also, the F-4C could not be made into the RF-4C by the addition of the cameras found on the reconnaissance version of the aircraft. It would have to be rebuilt structurally from the wheels up. Every aircraft in a fighter squadron today has the same degree of sophistication -- usually the maximum available for that particular type and model. The difficulty of determining a proper aircraft mix could be one reason why the mixed-force idea has not been pursued.

The high costs associated with advanced armament and electronic systems seem to indicate that it would be advantageous to employ some version of a mixed force. In terms of cost per target destroyed, it would seem less costly to use an unsophisticated aircraft where conditions permit. On the other hand, it would certainly be necessary

to maintain a certain number of high-cost, sophisticated fighters to use when conditions preclude the use of the basic machines. In his Rand report, Huschke says, "On the basis of development and manufacturing costs, and operational reliability and practicality, the best weapon system is the simplest one that will do the job." (Ref 37:2) Consider, for example, the Middle East where the dominance of good flying weather allows a simple tactical aircraft to be very effective most of the time; in Central Europe, the same aircraft would be useless because of weather a much greater percentage of the time.

This thesis was originally suggested by the Advanced Systems Analysis office of Aeronautical Systems Division (ASD/XR) which, at the time, was working on a similar study. Limited by time in their work, ASD/XR chose to evaluate close air support effectiveness by the following equation:

$$E = P[\ E_i\ ] \times P[\ D_i \mid E_i\ ] \times P[\ K \mid D_i, E_i\ ]$$

where $P[\ E_i\ ]$ = probability of being in weather state i

$P[\ D_i \mid E_i\ ]$ = conditional probability of successful weapon delivery

$P[\ K \mid D_i, E_i\ ]$ = conditional probability of killing the target.

ASD/XR acknowledged that the above approach could not adequately address the questions posed in a more detailed examination of the effects of weather and weather persistence on avionics requirements. (Ref 63) Since an even more elaborate expected value equation would still prohibit an in-depth investigation of the problem, they urged a more general method, one that could be applied to any aircraft in many situations, be formulated.

Rapp and Huschke of the Rand Corporation have begun preliminary work in this area but have concentrated mainly on the effects of weather on the force-mix problem. (Refs 35, 36, 37, and 38) They suggest,

> ... Attention should be focused on the problem of multiple environments ... Nature is but one principle variable, as are enemy defenses and target characteristics; others may also exist. Ultimately the kind of statistic that should be sought is, for example, the joint probability that target type X (requiring [avionics] system package A), protected by enemy defense type Y (requiring [avionics] system package B), will have to be attacked in weather type Z (requiring [avionics] system package C). Interrelationships among many combinations of requirements (targets, defenses, and weather) and solutions (systems packages) will be extremely complex; but one of the greatest values of this kind of analysis would be in bringing these interrelationships into sharper focus than they now are. (Ref 37:23)

Therefore, it was decided that a computer simulation model with great flexibility in the types of inputs it would accept would be a workable and satisfactory technique around which to build this study. A full description of the model will be found in Chapter II, but its goals can generally be described as:

(1) To capture those operational aspects of a close air support operation which interact with the variables of the study.

(2) To provide the analysts with appropriate measures of systems effectiveness.

(3) To contain enough flexibility to answer unanticipated questions and allow for future embellishment.

Terminology

At this point certain words, phrases, and concepts that are very important to this study should be clearly defined as they are used in this paper.

Close Air Support (CAS) is used as generally defined by tactical air doctrine. That is, direct support of friendly ground troops, at

their request, by tactical aircraft. It does not include the interdiction, air superiority, or armed reconnaissance missions.

Avionics. Avionics refers to electronic systems and armament systems which are used for navigation, electronic-counter-measures (ECM), target acquisition, and weapons delivery. Examples of such systems would be an inertial navigation system, radar homing and warning gear, infrared seekers, and television guided missiles.

Types of Aircraft. Throughout this study two versions of the same hypothetical fighter-bomber are used. One version is the basic airplane equipped with only those armament and electronic components that are necessary to perform the elementary close air support functions. This aircraft is referred to as Type 1 throughout the paper. Type 2 is the same aircraft fitted with additional advanced avionics gear that give it increased ECM capability and the capacity to launch and guide standoff weapons such as Maverick or laser-guided bombs. Although contrasting only two types of aircraft serves the needs of this study, the ideas could certainly be extended to examine the case of many degrees of avionics sophistication in a single aircraft.

Squadron. This study is concentrated on a squadron of twenty-four aircraft. A squadron may seem to be a small unit for analysis, but it should be remembered that a fighter squadron is the smallest air combat force which can be deployed and can operate autonomously from a forward base. Once again, the model can easily be expanded to include a much larger force.

Sortie. The terms sortie and mission are often used interchangeably, but there is a significant difference in their meanings. A sortie is a single flight by a single aircraft, whereas, a mission can

consist of a group of several aircraft flying several different sorties. Herein "mission" is used in the narrow sense and is synonymous with "sortie".

Plan of Presentation

Chapter II is a detailed description of the Simulation Model and its scenario.

Chapter III contains a general discussion of weather persistence models and a description of the Weather Model used in this study.

Chapter IV describes the Input Data that are required for the Simulation Model. In addition, the data used in an illustrative hypothetical example are also explained in this chapter.

Chapter V is an analysis of the Computer Generated Time-Series Data.

Chapter VI presents the Results of the Hypothetical Example.

Chapter VII presents the Summary, Conclusions, and Recommendations for further work.

The Appendix contains more detail on the Simulation Model, a copy of the computer program, a sample of the weather data, and descriptions of various statistical tests used in the analysis.

II. CLOSE AIR SUPPORT SIMULATION MODEL

In the study of complex military problems the analyst can pursue various courses of action depending upon the questions involved and the time available for study. For many problems, the analyst may rely upon standard mathematical techniques such as linear programming, queueing theory, dynamic programming or game theory to provide the necessary insight. Unfortunately, the application of many models force the analyst to work around pertinent aspects of the problem which do not fit the underlying assumptions of the technique. If time is available, the analyst may often attempt to develop an appropriate methodology to solve his problem. Unfortunately, this approach is impractical for most problems where decisions have to be made within short time frames. If the problem is involved with the actual operation of a system such as a close air support squadron, the analyst may benefit from observing the various components and transactions of interest. With this approach, however, the analyst lacks control over the critical variables of the problem. In addition, phenomena such as actual combat sorties are impractical, if not impossible, to produce.

One approach remaining is simulation. With this technique, the important aspects of the system under study are represented in mathematical form which is more amenable to investigation. This is the approach used in the present study of the close air support problem. The operation of the close air support squadron is represented by a computer program which includes those aspects of the operation germane to the problem. This chapter presents a brief introduction to the construction and use of this computer program.

As stated above, the simulation model represents only those aspects

of the close air support operation germane to the issues considered in this study. In essence, there is no "correct" size or scope of a simulation. The scope of a particular simulation must be determined primarily by the questions to be asked during the study and secondarily by the time available for construction of the model. For this study the scope of the simulation was fixed by (1) the decision to concentrate primarily on the operation of a single squadron of aircraft and to investigate the effects of weather and avionic equipment tradeoffs on that operation, and (2) the three month period of part-time effort allocated for model development. The above decisions were made on the basis of what the authors felt was a feasible amount of work for the time period of this study. As presently constructed the simulation model is incapable of addressing theater-level or total force-level issues. Nor is the model appropriate for analyzing detailed aircraft tactics. What the model does represent, however, is a balance between the aggregate and the microscopic level of detail.

One advantage of the simulation model, as currently developed, is its mathematical structure. The structure of the model is such that later modifications can be made with relatively little difficulty. In providing this feature, the model represents a flexible and responsive tool for addressing new and unanticipated questions related to the close air support mission. Throughout the remainder of this paper, suggestions for future modification and improvement of the model will be made where appropriate.

Since the principle intent of this study was limited to an investigation of the effects of weather and avionic equipment tradeoffs on the operation of a close air support squadron, the authors

decided that a relatively simple scenario would be used for the simulation. And while many details of the close air support operation were either omitted or simplified, it was felt that the inclusion of further details would confound the main effects of interest. Thus, the simulation program was developed to (1) reflect differences in aircraft survivability and effectiveness due to changes in weather and avionic equipment, (2) account for basic differences in reliability of various avionic equipment, and (3) account for differences in maintenance times associated with various avionic equipment. This approach is in general agreement with Kiviat who states that

> ... since people usually enter into explanatory models without knowing exactly what it is they are trying to explain, the pressure is to make everything as detailed as possible. As a general prinicple, this is incorrect. A model should only be as detailed as is necessary to answer the questions at hand ... (Ref 41:13)

Because of the stochastic nature of most aspects of a close air support operation, extensive use of the Monte Carlo technique was made throughout the model. As a result, a large portion of the input data consists of probability estimates.

The general scenario considers a squadron of close air support type aircraft operating out of a forward airbase. Within the squadron there can exist up to two different types of aircraft. For the present study, it was assumed that the only differences between these two types of aircraft were in on-board avionic equipment and the associated ordnance loads capable of being carried with this equipment.

Sortie requests for up to six different types of target/defense combinations are generated at random times throughout the day. As these requests are generated, they are filed in a queue which ranks them on the basis of expiration time of the target. Those targets

which have more immediate expiration times are considered first. Target expiration times were considered to be a realistic assumption for the close air support mission. If one were to consider interdiction sorties, this assumption might not be important.

As aircraft become available, sortie requests are filled according to their first and second choice of aircraft type. As considered in the model, the preference of aircraft type depended upon both the type of target and the current weather state. In this manner the model user maintains some control over the scheduling of aircraft.

Single aircraft flights are scheduled against single targets. The addition of multiple aircraft, multiple target sorties was considered during the development of the model, but was later rejected. The single aircraft, single target sortie was assumed adequate for demonstrating the effects of weather and avionic equipment tradeoffs on the close air support operation. Hence, the above addition was not considered to be a significant improvement of the model.

As suggested in Figure 1, once an aircraft is assigned to a sortie, the aircraft proceeds to penetrate the area defenses located across the forward edge of the battle area (FEBA). If the aircraft survives, it flies on to the target area where a forward air controller is assumed to be operating. If the aircraft's avionics are operating and the forward air controller is available, the aircraft makes its first pass at the target. Success of the sortie is dependent upon the attacking aircraft both surviving defenses at the target site and successfully delivering its weapons. The present model allows a maximum of two passes per sortie against each target.

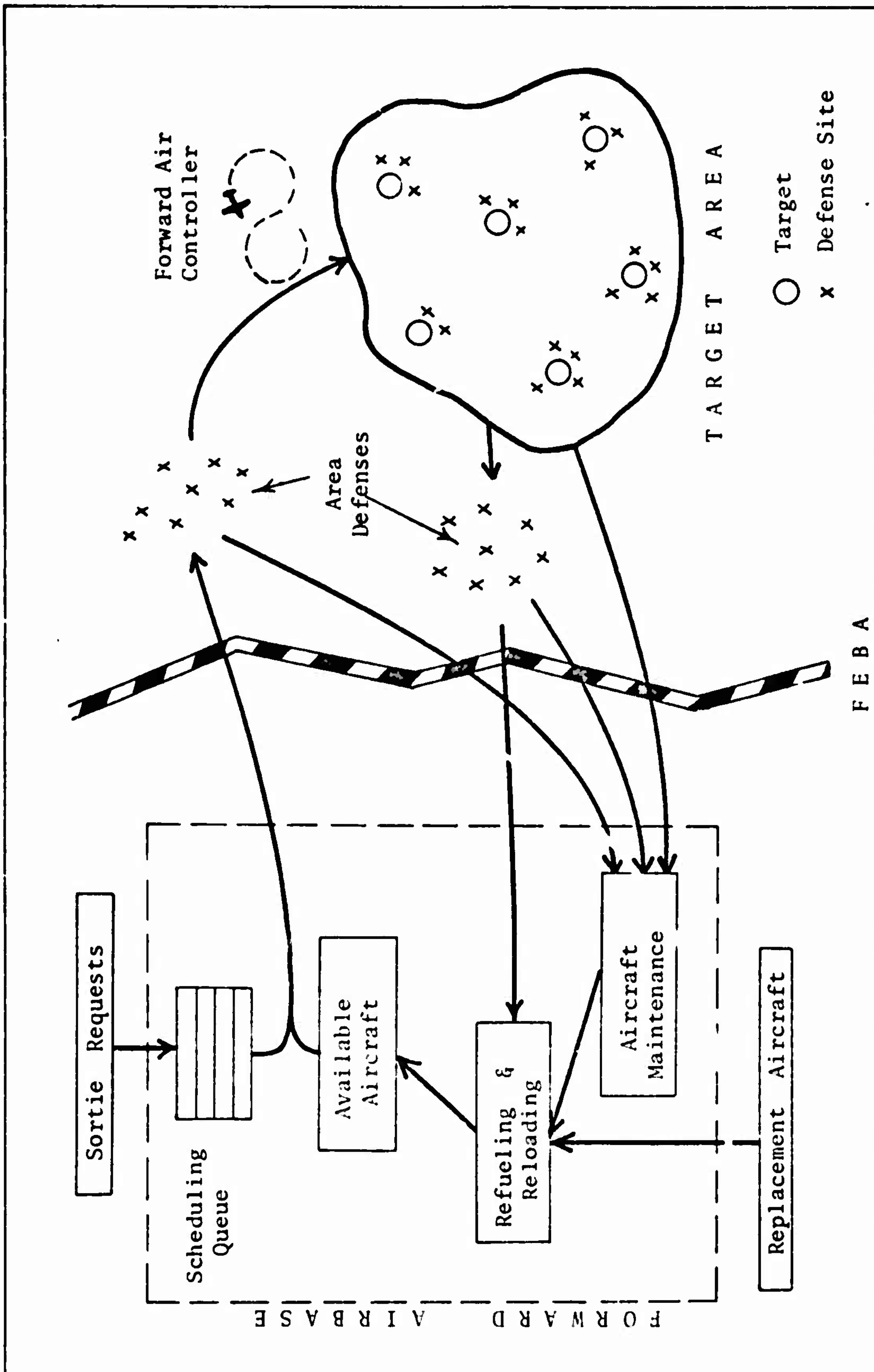


Figure 1 Close Air Support Model Scenario

Aircraft which have been damaged by enemy defenses are assumed to return to the forward airbase without completing the sortie. The same assumption is made regarding aircraft which have experienced an avionic equipment failure. If a sortie is aborted for some reason, the original sortie request is refiled in the scheduling queue so that the target may be given future consideration. The model checks the expiration time of each target before a sortie assignment is made. Hence, sortie requests which must be refiled may often be cancelled because the value of the target is no longer considered positive.

Aircraft returning to the forward airbase undergo appropriate maintenance actions before they are returned to the line. Several maintenance cycles are accounted for in the model. They serve primarily to account for the time an aircraft must spend being repaired for battle damage, being repaired for an avionic equipment failure, being refueled, and being reloaded with ordnance. While these maintenance actions do not represent the complete spectrum of servicing and repairs encountered by an aircraft, they do highlight the differences in reliability and maintainability between the two types of aircraft considered in this study.

Aircraft destroyed by enemy defenses are assumed to be replaced within twelve hours of their loss. This last assumption represents a desire during this study to keep the number of aircraft reasonably constant for the squadron.

The model description presented in this chapter is intended to be only a brief introduction to the operation and underlying structure of the simulation. Appendix A expands on this discussion with further details and also serves as a user's manual for the simulation model.

We now turn our attention to the use of the simulation model for selecting an optimum mix of aircraft in a close air support squadron. The remainder of this Chapter is devoted to an overview of the measures of system effectiveness considered in this study. The next chapter expands on the weather model chosen for use in this simulation. Chapter IV introduces a hypothetical example which is used to illustrate the required data inputs for the simulation and demonstrate the capabilities of the model. Chapter V investigates many of the typical problems encountered with the use of this type of simulation model. Finally, Chapter VI presents the results of using the model to analyze the hypothetical example introduced in Chapter IV.

As noted previously, the scope of the simulation was determined primarily by the authors' desire to investigate the effects of weather and avionic equipment tradeoffs on the operation of a single close air support squadron. Accordingly, the measures of system effectiveness considered in this paper are confined to this level of aggregation. Questions ultimately related to theater-level or total force level effectiveness cannot be addressed within the confines of the present paper.

Since the effectiveness of a system is defined in relation to its mission, the analyst must first ask what is the mission of a close air support squadron? Quite briefly, the mission of a close air support squadron is to provide timely air strikes for assisting in the defense of friendly ground troops. Admittedly, this narrow description is not totally reflective of the complex and sometimes vague mission requirements for this type of aircraft squadron. However, time limitations force this study to simplify and reduce the problem to a workable

proportion. In a practical sense, the selection of a measurement of system effectiveness must do two things. First, the measurement must reflect the essence of the problem at hand. Although a verbal description of the system's mission cannot be totally captured in terms of ratios or numbers on a scale, the measurement chosen should be highly correlated to the accomplishment of that mission. Secondly, the measurement must be definable in a reasonable and easy manner. Without such a measurement, the analyst is unable to proceed beyond an intuitive analysis of the problem. An obvious result of this necessary simplification is that the analyst is unable to totally express the amount of goodness in a particular system: he must leave some room for subjective opinion. For this reason, the authors fully appreciate the worth of personal judgment in evaluating the effectiveness of a given system. Furthermore, the authors do not pretend that the entire measurement of system effectiveness can be determined absolutely on a scale of numbers. This report shall, however, continue with the assumption that certain numerical measurements can be used to judge a great deal of the merit of a particular system in relation to alternative systems. And it is this type of measurement which is explored below.

Consider now two aspects of the mission as stated above. First, the requirement for air strikes suggests that the basic measurement of system effectiveness ought to be related to target destruction potential. This measurement can be made indirectly through the number of targets destroyed by the squadron in specified situations. This type of measurement can be obtained quite easily from the simulation model. Unfortunately, there are a great number of different situations in which the analyst might test the squadron's ability to destroy targets.

He now has to ask what is the most representative situation for measuring this ability? To further compound the problem, there are a variety of operational factors such as the number of targets assigned per sortie, the number of allowable target passes per sortie, the penetration tactics used against area defenses, and others which influence the squadron's ability for destroying targets. If the analyst allows both physical and operational factors to vary together, he has confounded the experiment. This, in turn, requires that additional studies to be performed so as to separate the influence of these two factors. Again, time available to this study limits the amount of work which can be performed and limits the number of variable factors in this analysis. During the analysis of the hypothetical example, the authors chose to hold many factors (both physical and operational) constant. However, it should suffice to say here that they still considered many of these factors to have a significant influence on the close air support operation.

The second aspect to be considered in the close air support mission is that the support given by the squadron must be timely. The word timely is important in this situation since close air support targets are relatively transient compared to targets associated with, say, an interdiction mission. Implications of this concern are seen as we again address the question of destruction potential. Close air support targets are simply not available to strike at will. Each of these targets occur at random times and have a lifetime associated with them. If a squadron is unable to quickly respond to these targets, their value is lost. Hence, the analyst must consider the measurement of destruction potential as being made relative to a list of transient

target opportunities. Although this transient nature is accounted for in the simulation model, the analyst must continue to be aware of its implications in the interpretation of system effectiveness.

Time is important to the simulation in one other respect. The effectiveness of the close air support system as related through the number of targets it destroys is significantly influenced by the weather state. Since the weather state is a time-dependent variable, it is important to be aware of how squadron effectiveness is, in turn, transformed into a time-dependent variable. If the analyst investigates only steady-state or expected value measurements of effectiveness, he is missing half of the information available to the decisionmaker. The use of a simulation model made it possible to describe the dynamic nature of system effectiveness and part of this study was devoted to studying this nature. Specifically, Chapter V introduces the time-dependent nature of the number of targets destroyed per day by the squadron and addresses questions related to steady-state conditions, the effects of initial conditions, and autocorrelation. Chapter VI later discusses possible implications of this information to the decision-maker.

Of equal interest to the analyst is system cost. This is the other half of the coin which tells us the price one must pay to achieve various levels of effectiveness. Not all costs can be expressed in terms of dollars, just as it is impossible to express all of the mission in terms of a numerical scale. Following an earlier argument presented for effectiveness measurements, the authors must state here that time limitations force them to take a simplified approach in defining system costs. Again, they believe that while such an approach provides useful information for the comparison of alternative systems,

it does not reflect all of the costs of interest to the decision-maker.

Just as the mission of the close air support squadron was defined earlier, one can now define the major areas of system cost. First, there exist procurement costs for both the aircraft and the additional avionic equipment considered during the tradeoff studies. In addition, there exist costs of initial spares, AGE, and any other initial resources used in the system. Finally, the analyst must consider operating costs which include maintenance, recurring spares, POL, and other recurring costs associated with the operation of the close air support squadron. Operating costs, however, depend upon the time period and conditions involved. Is it appropriate to consider only operating costs incurred during war? If the analyst uses peacetime operating costs, what is an appropriate length of time? Because the close air support squadron must be maintained over a period of years in anticipation of war, the authors considered peacetime operating costs to be an appropriate choice. In a sense, these costs are the true costs of ownership involved with the squadron and they are the true decision costs for our problem. For this study an arbitrary period of ten years was assumed for the calculation of peacetime operating costs. While this assumption allows one to define a reasonable cost measure for each alternative system, it is not meant to imply anything about the actual lifetime of the squadron.

Does the use of a ten year, peacetime operating cost imply that all wartime costs are insignificant to the problem? The answer is no. Many wartime costs such as maintenance costs, attrition costs, and ordnance costs are very important. In addition, the loss of pilots is

of paramount interest even though it is impossible to express this type of loss in terms of dollars. For these reasons this study examines several wartime costs associated with the operation of a close air support squadron. Chapter VI presents many wartime costs for our hypothetical example and discusses their importance to the decisionmaker.

In summary, this chapter has introduced the analysis tools used during this study to investigate the effects of weather and avionic equipment tradeoffs on the operation of a close air support squadron. As stated earlier, the scope of the problem investigated as well as the capabilities of the analysis tools developed were primarily limited by the time available for this research effort. The remainder of this paper is devoted to (1) a demonstration of the analysis tools on a hypothetical problem, and (2) explorations of special problems associated with the analysis of a close air support operation.

III. WEATHER MODEL

The weather is one of the most influential factors in determining the success or failure of an aerial mission. Aircraft are at the mercy of the elements from the time they begin their take-off roll until they have taxied off the runway at their destination. In the conduct of CAS operations, weather in the target area is very critical, because aircrews must be able to maintain visual contact with the target while they are maneuvering to deliver their ordnance. Ground operations which rely on CAS for their success can become victories or disasters depending on the weather conditions at the time of the engagement. There is a well-known anecdote about General George Patton ordering a prayer for good weather during the allied counterattack at the Battle of the Bulge in World War II. Some writers believe that the clearing of the weather on 24 December 1944 (as per Patton's request) doomed the German offensive and opened the way for the final Allied thrust across the Rhine. (Ref 42:296) It has long been suspected that the North Vietnamese plan their offensives to coincide with poor flying weather. At Dien Bien Phu the only means of resupply available to the French was via air-drop. The poor, monsoon weather during the siege caused most of the ammunition and supplies dropped by the French to fall within the Viet Minh lines and virtually negated any attempt at close air support by French fighters. (Ref 15:213 & 350) Finally, the Spring of 1972 invasion of South Vietnam by the North Vietnamese was shielded by bad weather during its early days. The North Vietnamese were free from air attack long enough to shatter the South Vietnamese units along the Demilitarized Zone and drive them back to the lines held under the 1973 cease-fire agreement. Had not the weather cleared

enough to allow massive tactical air strikes by USAF and VNAF forces, these lines might have been much further south. (Ref 61:61)

Aircraft mission performance in poor weather conditions can be improved significantly by the use of appropriate avionics systems. However, the evaluation of performance gained by "anti-weather engineering" is not a simple problem. One misleading implication of the phrase "all-weather aircraft" is that an all-weather system can do a job as effectively in bad weather as in good weather. Obviously this is not always true. For example, an instrument landing system allows an aircraft to land under conditions of low ceiling and poor visibility, but at a higher risk, a much slower rate, and a higher rate of fuel consumption than if the weather was clear. Another connotation of "all-weather" is that such systems are always useful, and are therefore used under all weather conditions. There is a fraction of the time when the weather will be too bad for even the best all-weather system to fly, and, as Huschke states,

> ... In reality, whenever a simpler, cheaper, fair-weather alternative is available, an all-weather system tends to become a "bad-weather" system. Consequently, the usefulness of an all-weather system becomes a rather direct function of the frequency of weather conditions that would prevent using the fair-weather alternative. (Ref 37:2)

Because weather conditions would seem to have great effect on the optimum mix of simple and sophisticated aircraft, it was decided that special care should be taken in determining a realistic weather model to use in the simulation. In keeping with the design of the simulation, a dynamic weather model was desired; one that would not be restricted to any particular geographic area or climate. A model currently in use at Air Force Studies and Analysis (Ref 24) seemed adequate, but was designed to answer certain specific questions about the effects of

weather persistency in a specific area. The iterative approach used in the model resulted in very accurate approximations to actual weather frequency-of-occurrence data, but did not seem feasible for use in this study because of the size and complexity of the model. Work at the Rand Corporation in the <u>Weather and Warplanes</u> study series (Ref 36, 37, & 49) has so far concentrated mainly on the problem of determining the value of accurate weather forecasting in military operations and the effects that good forecasting would have on the force-mix question. Because in addressing the force-mix question they used two undefined weather states called "good" and "bad" and ignored the short term effects of weather persistency, their approach did not seem suitable for use in this work. (Ref 37:34) (Ref 49:2) Others have used weather models based on the random selection of weather states according to the expected frequency-of-occurrence of the different states. Long-term climatological records are kept for many locations, and they make it quite easy to estimate the percent of the time a certain weather condition can be expected to occur. The use of these frequencies in describing weather behavior is usually adequate for analyzing long-run effects, but they have one serious drawback when short-term questions are addressed. For example, when planning a military operation that will last a period of weeks or months it will probably suffice to know that bad weather can be expected to prevail thirty percent of the time. However, if the endeavor is projected for a number of hours or days, the commander would like to know not only what the probability of bad weather is today, but if it is bad weather today will it be bad weather again tomorrow? In other words, he is interested in the persistence of some weather conditions once they occur. If, for instance, the Arab-Israeli Six-Day War had been started during a period of very low

ceilings and visibility, and if poor weather had persisted for four or five days thereafter, there could conceivably have been a different outcome to the war, and it certainly would have lasted more than six days. In order to maintain the flexibility of studying short-run effects as well as long-run effects with this simulation model, it was decided that the weather model should reflect weather persistence as well as weather frequency.

The Data

Huschke says, "Essentially all weather-effect problems ... require probabilistic answers. Therefore, the basic source of weather data has to be long-term climatological records to ensure statistical accuracy ..." (Ref 5) Modern data processing has made such long-term data available from the USAF Air Weather Service and the United States Weather Service. In fact the analyst may be troubled with trying to handle too much data rather than forced to cope with a dearth of information.

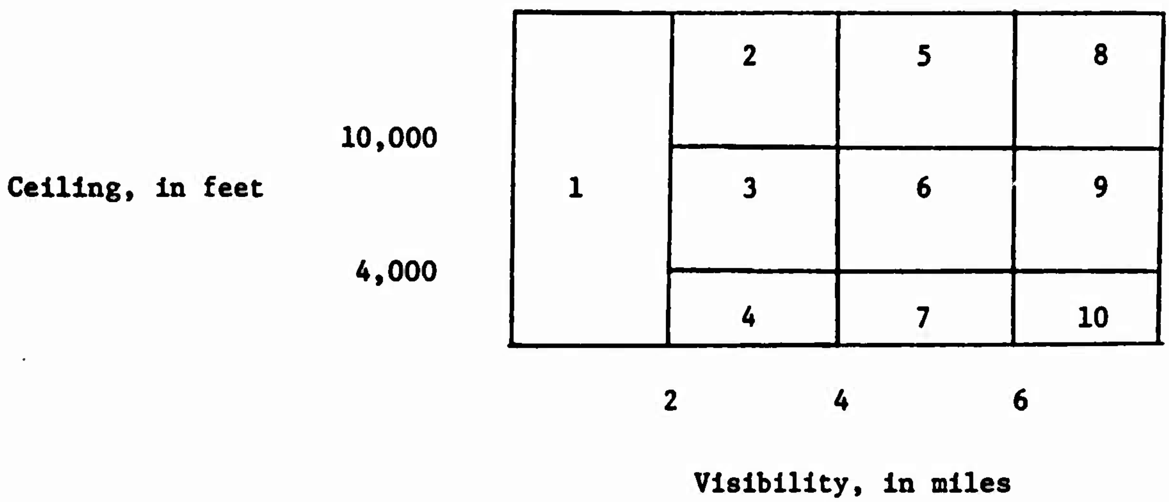
The weather data used in this study was supplied second-hand through Captain Jon R. Thomas at Air Force Studies and Analysis. (Ref 59) He obtained the data from the Data Processing Division, USAF ETAC. (Ref 62) The data consisted of the percent frequency-of-occurrence and percent frequency-of-duration of selected ceiling-visibility categories. They were compiled from hourly ceiling and visibility observations at Bitburg Air Base, Germany from April 1952 through December 1970. The data were tabulated by month, weather category, start-hour (0000--2300 Local Standard Time), and duration of from one to greater than thirty-nine hours. (For an example of the data format, see Appendix) Total observations used to obtain a frequency were listed under each number. Percent frequency-of-duration

data were based on between 12,200 and 13,700 total observations for each month and each weather category. Ten mutually exclusive weather categories (states) were defined, and they are shown in Figure 2.

The data were especially suited for studying the question of weather persistence. For example, for each month and weather state, the data gave the percent frequency-of-occurrence of that weather condition at each hour of the day and the average frequency for the twenty-four hour period. In addition, the data gave the percentage of the time that the weather condition lasted one hour, two hours, three hours, and so on up to thirty-nine hours, given that it had occurred at the initial start-hour. To clarify the nature of the data, here is a brief example: In the month of February, the prevailing weather at 0600 was state one 26.4 percent of the time. One hour later, 22.8 percent of the observations indicated that weather state 1 still prevailed, and eight hours later, 6.7 percent of the time it was still weather state 1. Finally, one can see that given weather state 1 was in effect at 0600, 0.6 percent of the time that weather condition persisted for greater than thirty-nine hours. From this information, one can compute the mean persistence time for any weather category and month.

Analysis of Data

If the data happened to reflect some well defined probability distribution, the analysis would be greatly simplified. A plot of a portion of the data (Figure 3) seems to indicate that some sort of decay function such as the exponential or geometric distribution functions may be the underlying random process. The discrete nature of the hourly weather observations made the geometric seem more appropriate.



Category (State)	Visibility (Miles)	Ceiling (Feet)
1	< 2	≥ 0
2	≥ 2 but < 4	$\geq 10{,}000$
3	≥ 2 but < 4	≥ 4000 but $< 10{,}000$
4	≥ 2 but < 4	< 4000
5	≥ 4 but < 6	$\geq 10{,}000$
6	≥ 4 but < 6	≥ 4000 but $< 10{,}000$
7	≥ 4 but < 6	< 4000
8	≥ 6	$\geq 10{,}000$
9	≥ 6	≥ 4000 but $< 10{,}000$
10	≥ 6	< 4000

Figure 2 Definition of Weather States

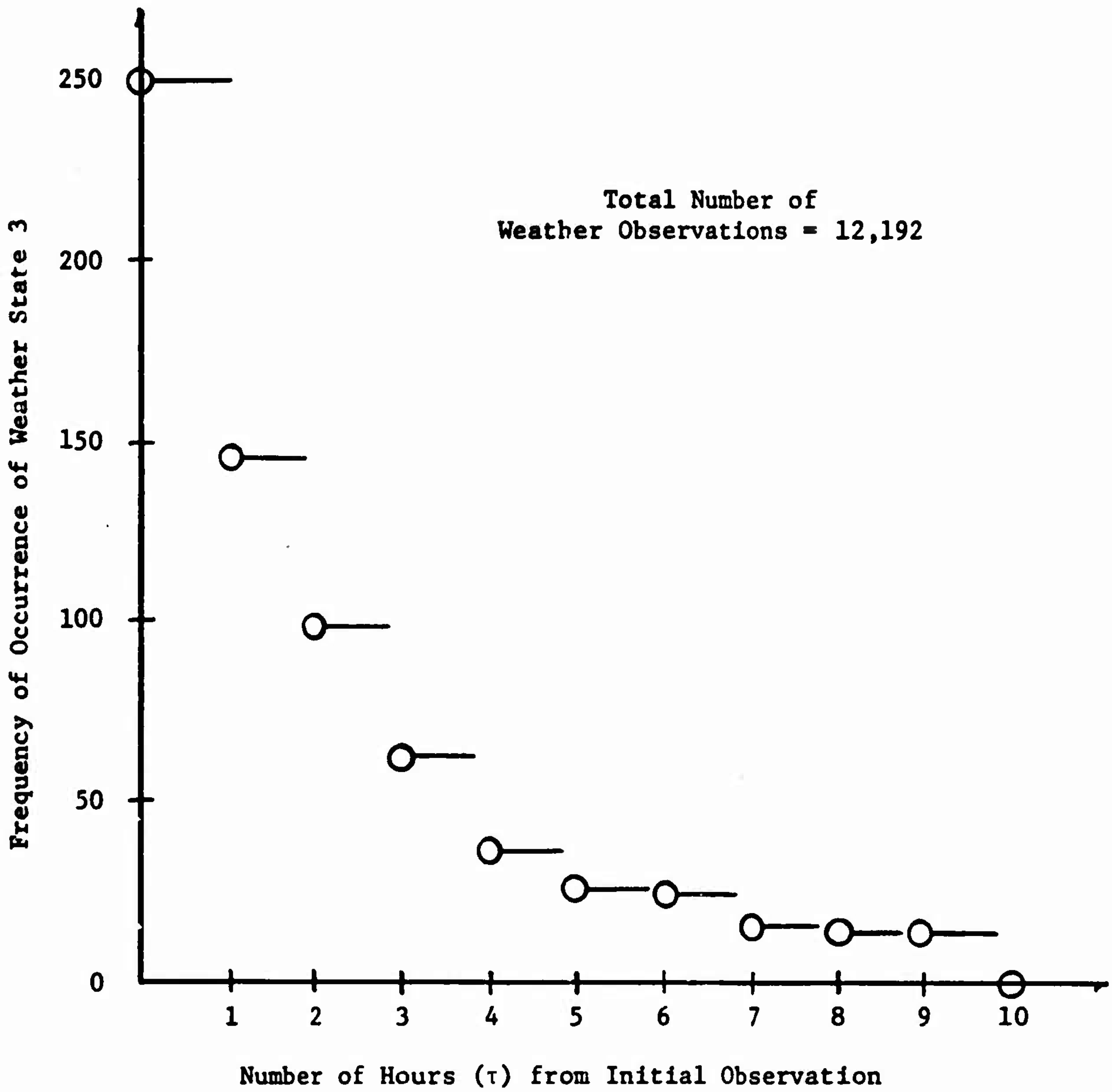


Figure 3. Plot of Weather Persistence Data
Bitburg, Germany -- February
Weather Category 3

To determine if the underlying probability distribution function of the data could be approximated by the geometric distribution, the chi-square goodness-of-fit test was applied. In the chi-square test, a random sample of size n is drawn from a population with an unknown cumulative distribution function F_X. The desire is to test the null hypothesis

$$H_o: \quad F_X(x) = F_o(x) \qquad \text{for all } x$$

against the alternative hypothesis

$$H_a: \quad F_X(x) \neq F_o(x) \qquad \text{for some } x$$

where $F_o(x)$ is a completely specified distribution function -- in this case, the geometric. (Ref 26:69)

The geometric distribution is a discrete probability density function. Suppose that some experiment E is performed with interest only in the occurrence or non-occurrence of an event A. Assume that E is performed repeatedly and independently, and that on each repetition the probability that A occurs is p (P[A] = p), and the probability of A not occurring, $\bar{A}$, is $1 - p = q$, where p and q remain the same for all repetitions. If the random variable X is defined as the number of repetitions required up to and including the first occurrence of A, then $P(X = x) = pq^{x-1}$, where x is the number of repetitions, is the geometric probability density function. The mean of the geometric distribution is given as $E(X) = \frac{1}{p} = \frac{1}{1-q}$. (Ref Meyer:170) In this application, the event A was defined as the transition from the weather state under consideration to some other weather state, and the experiments, E, were the hourly weather observations. Therefore, the complement of A, $\bar{A}$, reflected the persistence of the weather state.

The random variable T was used to describe the number of repetitions required for the first transition, so that

$$P(\,T = \tau\,) = pq^{\tau - 1}, \quad \tau = 1, 2, \ldots$$

In the chi-square test, the data must be categorized for analysis. The hourly weather observations provided a natural classification method and were used as the categories. The only exception to this was when the number of transitions was less than ten in which case categories were combined to form a single category containing ten or more transitions. (Ref 54:46) Therefore, the total number of observations (transitions) in a test was n and the total number of categories was k, where $k \leq n$. (The terms "observation" and "weather observation" should not be confused. "Observation" refers to an occurrence of the event A, whereas a "weather observation" is the observing and recording of weather conditions at each hour of the day.)

A chi-square goodness-of-fit test was run for each of the ten weather states using data from the month of February. N observations were grouped into k mutually exclusive categories, and the chi-square statistic was computed by

$$\chi^2 = \sum_{\tau=1}^{k} \frac{(f_\tau - e_\tau)^2}{e_\tau}$$

where f_τ was the observed number of transitions, and e_τ was the expected number of transitions (based on the geometric distribution) for each time period $\tau = 1, 2, \ldots, k$. This statistic is distributed approximately as the chi-square distribution with $k - 1$ degrees of freedom. (Ref 26:70)

In order to compute the e_τ, the parameter q of the geometric distribution had to be estimated from the data. Meyer states that for goodness-of-fit tests, such estimates should be obtained by the method

of maximum likelihood. (Ref 45:333) The technique described in Freund (Ref 23:268) was used to find the maximum likelihood estimator for the geometric distribution. It is briefly illustrated below:

$$f(T;\ q) = pq^{\tau-1}$$

$$L(q) = p^n q^{\sum_{i=1}^{n} (\tau_i - 1)}$$

$$\ln L(q) = n \ln p + \sum_{i=1}^{n} (\tau_i - 1) \ln q$$

$$\frac{d \ln L(q)}{dq} = \frac{n}{1-q} + \frac{\sum_{i=1}^{n} (\tau_i - 1)}{q} = 0$$

$$\therefore\ q = 1 - \frac{n}{\sum_{i=1}^{n} \tau_i} .$$

The way this estimator was used is illustrated in the sample chi-square test in the Appendix.

The fact that a parameter had to be estimated from the data necessitated that the degrees of freedom of the chi-square distribution be reduced by one. (Ref 45:333) This meant that the χ^2 statistic was distributed approximately as $\chi^2_{k-2,\ 1-\alpha}$, where α was the significance level of the test. The details of how the test was performed for one weather state can be found in the Appendix.

The null hypothesis tested was H_o: The weather persistence data were from a geometric distribution, against the alternative H_a: The data were not from a geometric distribution. The hypothesis was tested for each weather state at the α = .05 and α = .01 significance levels. H_o could not be rejected at α = .05 for seven of the ten weather states, and H_o could not be rejected at α = .01 for nine of the ten. One weather state failed the test at all reasonable significance levels.

These results seemed to be a good indication that the weather data were geometrically distributed; however, there was still room for doubt because of the few times that the hypothesis was rejected. Also, there are doubts concerning the power of the chi-square test. Cochran says,

> Considering first the criticisms of χ^2 itself, the name "goodness-of-fit" is misleading, because the power of the test to detect an underlying disagreement between theory and data is controlled largely by the size of the sample. With a small sample, an alternative hypothesis which departs violently from the null hypothesis may still have a small probability of yielding a significant value of χ^2. In a very large sample, small and unimportant departures from the null hypothesis are almost certain to be detected. Consequently, when χ^2 is non-significant the amount by which the null hypothesis has been strengthened depends mainly on the size of the sample.
> (Ref 7:335)

Cochran suggests that one way of strengthening the chi-square test is to combine it with an alternative test. (Ref 8:418) Massey maintains that the Kolmogorov-Smirnov (K-S) goodness-of-fit test is a very good alternative to the chi-square test, and he presents evidence that the K-S test is, in most cases, more powerful. (Ref 44:76)

Therefore, it was decided that the K-S goodness-of-fit test should be applied to the data in order to strengthen or firmly discount the results of the chi-square tests. A description of the K-S test follows.

The empirical distribution function is defined as

$$S_n(\tau) = \begin{cases} 0 & \text{if } \tau < T_{(1)} \\ \frac{k}{n} & \text{if } T_{(k)} \leq \tau < T_{(k+1)} \quad \text{for k-1, 2, ..., n-1} \\ 1 & \text{if } \tau \geq T_{(n)} \end{cases}$$

where $T_{(1)}, T_{(2)}, \ldots, T_{(n)}$ are the order statistics of the sample. $S_n(\tau)$ is sometimes called the statistical image of a distribution. A random sample $T_1, T_2, \ldots, T_n$ is drawn from a population with an unknown cumulative distribution function, $F_T(\tau)$. For any value of τ, empirical

distribution of the sample, $S_n(\tau)$, provides a consistent point estimate for $F_T(\tau)$. The Glivenko-Cantelli theorem states that the step function $S_n(\tau)$, with jumps occurring at the values of the order statistics for the sample, approaches the true distribution function for all τ. Therefore, for large n, the deviations between the true function and its statistical image, $|S_n(\tau) - F_T(\tau)|$, should be small for all values of τ. This result suggests that the statistic $D = \sup |S_n(\tau) - F_T(\tau)|$ is, for any n, a reasonable measure of the accuracy of the estimate. (Ref 26:75-6) Critical values for the K-S test have been tabulated as $D_{n,\ \alpha}$, where n is the sample size, and α is the level of significance. (Ref 4:426) The null hypothesis is the same as for the chi-square test; H_o: The data is geometrically distributed, against H_a: The data is not geometric. The rejection region for this hypothesis was for $D \geq D_{n,\ \alpha}$, reject H_o at significance level α.

For continuous distributions, the D statistic is distribution free (i.e., its pdf does not depend on $F_T(\tau)$). (Red 26:76) This cannot be said for discrete distributions such as the geometric. In fact, it should be noted that all the theoretical properties of the K-S statistics require the assumption that F_T be continuous, since this is necessary to guarantee their distribution-free nature. The properties of the empirical distribution function given above and the Glivenko-Cantelli theorem do not require this continuity assumption, however. (Ref 26:85) Therefore, the K-S test is not restricted to continuous distributions as was once believed. (Ref 44:68) It has been shown that if the D_n values based on a continuous F_T are used in a discrete application, the true significance level is at most α. Hence, the exact same procedure is used for discrete F_T as for continuous, remembering that the test is more conservative. (Ref 26:85)

The K-S test was applied to the same data as the chi-square test, and in no case could the null hypothesis be rejected at the .01 significance level. An example of how the tests were conducted will be found in the Appendix. Although the use of a discrete distribution and the estimation of a parameter to define $F_T(\tau)$ make the K-S test more conservative than normal, these results coupled with the chi-square test results seemed to reasonably support the assumption that the weather persistence data can be approximated by a geometric probability density function.

The Markov Approach

The acceptance of the geometric distribution as the underlying density function of the weather persistence data suggested an interesting approach to the problem. Howard has shown via transform analysis that in a Markov process, the number of time periods, τ_i, that a state i will hold before the process transitions to another state j is geometrically distributed with a parameter that depends only on p_{ii}. For example,

$$p(T = \tau) = (1 - p_{ii})p_{ii}^{\,T - 1} \qquad T = 1, 2, \ldots$$

If a process is in state i, then p_{ii} is the probability that it will stay in state i at the next transition. By this definition p_{ii} is the same as q, the parameter of the geometric distribution defined earlier. In addition, the mean holding time is

$$\bar{T}_i = \frac{1}{1 - q} = \frac{1}{1 - p_{ii}} \ . \qquad \text{(Ref 34:241)}$$

All this implies that a Markov process may be a good way to model the weather in a dynamic simulation.

The Markov process is based on the Markovian Assumption, which is:

Only the last state occupied by a process is relevant in determining its future behavior. In other words, "the probability of making a transition to each state of the process depends only on the state presently occupied." (Ref 34:3) This assumption is very strong, so strong in fact that there are few physical systems that could be expected to be so memoryless. The assumption certainly is not intuitively appealing when applied to the weather. Howard says, however, "No experiment can ever show the ultimate validity of the Markovian Assumption; hence, no physical system can ever be classified absolutely as either Markovian or non-Markovian -- the important question is whether the Markov model is useful." (Ref 34:4) Meyer quotes Professor J. Neyman, saying,

> Whenever we use mathematics in order to study some observational phenomena we must essentially begin by building a mathematical model (deterministic or probabilistic) for these phenomena. Of necessity, the model must simplify matters and certain details must be ignored. The success of the model depends on whether or not the details ignored are really unimportant in the development of the phenomena studied. (Ref 45:1)

Howard goes on to say, "If the Markovian Assumption can be justified, then the investigator can enjoy analytical and computational convenience not often found in complex models." (Ref 34:4)

Feller has shown that the geometric distribution is the only discrete distribution that has lack of memory in the waiting-time process. (The exponential has this property for continuous densities.) This means that a system which can be described by a geometric distribution has no memory from one trial to the next. (Ref 17:328) For example, suppose that event A has not occurred during the first ten repetitions of the experiment E. Then the probability that it will not occur during the next ten repetitions is the same as the probability it would not occur during the first ten repetitions. In other words, the information of no successes is "forgotten" so far as subsequent

calculations go. (Ref 45:172) But this is precisely the meaning of the Markov Assumption; therefore, the presence of the geometric distribution in the weather data seems to justify the use of a Markov model to describe the weather process.

The Model

Captain Jon R. Thomas at Air Force Studies and Analysis (Ref 59) suggested a method for constructing a weather transition probability matrix from the weather persistence data on hand, and many of his ideas were used in the following model. In constructing the model, the ten weather categories previously described were defined as the ten mutually exclusive weather states of the Markov process; transition from one state to another can only occur at each Δt time increment. Of course, the number of weather states used in the model is flexible and can be set according to the purpose of the study. The weather transition probability matrix, W, is an n x n matrix where n is the number of weather states defined in the process.

The elements of the matrix are the probabilities of transitioning from one state, i, to another state, j, at the next Δt time increment: $W = [\ p_{ij}\ ]$, $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, n$. Notice that virtual transitions are allowed. A virtual transition is a transition from a state back to itself, so that in virtual transitions there is no actual change of state. (Ref 34:243) This means the p_{ii}, $i = 1, 2, \ldots, n$ of the matrix W can be equal to or greater than zero.

The Δt time increment is the period of time from one transition until the next transition takes place in the Markov process. This increment can be defined in any way that is amenable to the system being modeled. Since the weather data used in this study were based on

hourly weather observations, one hour was chosen as the Δt time increment. (See Figure 3)

It was shown above that the persistence for a weather state i can be approximated by a geometric distribution, and that p_{ii} is the parameter of that distribution. The mean holding time is

$$\bar{\tau}_i = \frac{1}{1 - p_{ii}} .$$

If the mean time until transition (a_i), in hours, is calculated from the weather data, then $\frac{a_i}{\Delta t}$ will be the mean holding time for weather state i (in numbers of time periods). Therefore,

$$\bar{\tau}_i = \frac{a_i}{\Delta t} = \frac{1}{1 - p_{ii}}, \text{ and}$$

$$p_{ii} = 1 - \frac{\Delta t}{a_i} .$$

The last equation is an expression for the calculation of the diagonal elements of the transition probability matrix. In all the work done for this thesis, Δt = 1 hour, and a_i was calculated using the maximum likelihood estimator illustrated in the chi-square test in the Appendix.

The calculation of the off-diagonal elements of the matrix W is a bit more complicated and is based on solving the following set of simultaneous equations:

$$(1) \quad \sum_{i=1}^{n} v_i = 1$$

$$(2) \quad v_j - \sum_{i=1}^{n} p_{ij} v_i = 0 \qquad j = 1, 2, \ldots, n - 1 ,$$

where n is the number of weather states in the system, v_i is the frequency-of-occurrence of each weather state, and p_{ij} is the ijth element W.

The procedure is arbitrarily to select values for the non-zero,

off-diagonal p_{ij} subject to the constraint $\sum_{j=1}^{n} p_{ij} = 1$, $i = 1, 2, \ldots, n$. Equations (1) and (2) are then solved simultaneously for the v_i. These values for the v_i are compared with the actual frequencies-of-occurrence from the data, and if they are close, then the estimated p_{ij} are the transition probabilities used in the matrix. If the v_i do not closely approximate the actual frequencies (the analyst must decide how close he wants these values to be), then the p_{ij} are adjusted accordingly and the system is solved again. This procedure is repeated until acceptable v_i are obtained.

The method is quite tedious when done by hand for large transition probability matrices; however, the use of a computer program that solves systems of simultaneous homogeneous equations makes the task much easier. The computer program SIMEQN on the GE-600 computer was used to find the matrices used in this thesis, and this program, along with the simplifying assumptions to be described, made it possible to find the p_{ij} in only five or six iterations.

Two matrices were constructed via the above method for use in this study. One was compiled from weather data for the month of January to simulate bad weather conditions, and the other was compiled from July weather data to simulate good weather conditions. They are presented in Figures 4 and 5. A third matrix, an identity matrix, was used in parts of the analysis that required the weather to remain in a constant state throughout a simulation run.

To simplify the calculation of the off-diagonal elements of the matrices, two assumptions were made. The only purpose of the assumptions was to decrease the number of non-zero p_{ij} that had to be computed. They have no relationship to the theory behind the model, and the model can be used without these assumptions. The assumptions were: (1) Only

.904	.022	.011	.063	0	0	0	0	0	0
.100	.776	.013	0	.111	0	0	0	0	0
.161	.028	.708	.079	0	.024	0	0	0	0
.152	0	.023	.763	0	0	.062	0	0	0
0	.030	0	0	.733	.020	0	.217	0	0
0	0	.067	0	.095	.667	.151	0	.020	0
0	0	0	.091	0	.014	.691	0	0	.204
0	0	0	0	.056	0	0	.883	.061	0
0	0	0	0	0	.011	0	.112	.722	.155
0	0	0	0	0	0	.104	0	.055	.841

Figure 4

One-Hour Transition Probability Matrix

For January

.614	.100	.086	.200	0	0	0	0	0	0
.100	.538	.162	0	.200	0	0	0	0	0
.175	.150	.375	.150	0	.150	0	0	0	0
.100	0	.200	.463	0	0	.237	0	0	0
0	.074	0	0	.572	.064	0	.290	0	0
0	0	.084	0	.200	.466	.100	0	.150	0
0	0	0	.135	0	.135	.480	0	0	.250
0	0	0	0	.030	0	0	.899	.071	0
0	0	0	0	0	.060	0	.120	.720	.100
0	0	0	0	0	0	.048	0	.192	.760

Figure 5

One-Hour Transition Probability Matrix

For July

ceiling or visibility can change during a transition; never both. (2) In one transition the weather can only go to an adjacent weather state as illustrated in the diagram of Figure 2. For example, the weather cannot go from state 1 to state 9 in one transition, so $p_{19} = 0$. Once again, these assumptions were only made to ease the calculations and have no effect on the overall usefulness of the weather model. It should be noted that all weather states are transient -- there are no trapping states. This means that any weather state can eventually be reached from any other state. This condition is realistic and is necessary for equation (2) to be valid.

The weather matrices constructed by the above model seemed to adequately fulfill the goals of representing short-term persistence and long-term frequency-of-occurrence conditions. To check the long-term nature of the January matrix, its steady state conditions were calculated. These steady state results are compared with the actual frequency-of-occurrence data in Figure 6. Further results due to using the matrices in the simulation model will be described in Chapter VI.

The Semi-Markov Process

During the research for the above Markov model, it became apparent that a discrete-time semi-Markov process might be a more flexible way to model the weather. The advantage is that the model would no longer be dependent on the state holding times being geometrically distributed. The reason that the semi-Markov model was not pursued is that it would result in a three dimensional matrix to describe the weather process. This is not "bad" in itself, but the programming language used in the simulation model (SIMSCRIPT) only allows two-dimensional arrays in the program.

Weather State	Actual Frequencies	Model Steady State Frequencies
1	25.9	23.7
2	3.9	3.3
3	1.9	2.1
4	11.4	10.5
5	4.4	5.5
6	1.6	1.1
7	8.8	9.2
8	15.7	17.5
9	4.7	7.7
10	21.8	19.4

Figure 6

Steady State Results and

Frequencies-of-Occurrence for January

Howard (Ref 34:577) gives a very complete discussion of the semi-Markov process, and it is suggested that further modeling work on the weather could be well spent in investigating the semi-Markov approach.

IV. DESCRIPTION OF INPUT DATA REQUIREMENTS

The aim of this chapter is to describe the input data that are required for the simulation model. Additionally, a description of the data used to exercise the model in a hypothetical illustrative problem will be found here. The only purpose of this hypothetical problem was to demonstrate an application of the model, and no attempt was made to address any real questions through this example.

A primary concern in the development of the simulation model was the flexibility of the input data requirements. This was in keeping with the objective of creating a model that would be useful to analysts studying similar problems in the future. The flexible aspects of the input data will be demonstrated in the following discussion. In addition, one of the great advantages of the simulation approach is that it is very suitable for analyzing the sensitivity of the output results to changes in the input information; the input requirements for this study were designed with this facet in mind. As has been previously described (Chapter II), this technique was used extensively in generating the output information for this paper.

To be of value to future users the model should only require input data that can be obtained with a reasonable degree of effort. Therefore, an attempt has been made throughout this chapter to outline possible data sources.

To avoid problems with security classification, no specific aircraft was the subject of research. Likewise, the data used to demonstrate the applications of the model come from no specific airplane, weapon, or study. Reasonable estimates for much of the data used were obtained from various agencies and individuals, described herein, and every

effort was made to insure that no classified data appear in this paper. In cases where "ball park" numbers were not available or were impractical to obtain, estimates were made by the authors based on previous work and operational experience. These instances are few and do not involve areas that have significant impact on the results of the study. It is believed that the data used in this work present a realistic picture of the close air support situation modeled without using classified information. This should enable the reader to make judgments on how valuable the model will be if used with real data. Of course, a future user of this model or of an extension of it could employ data from actual aircraft, weapons, targets, and combat situations with no difficulty.

The data utilized are based on the type of combat engagement that might be expected in Western Europe. It is assumed that only conventional weapons are employed by the ground and air forces. Typical combat encounters between ground forces would include firefights between opposing infantry units, artillery barrages, and armored vehicle maneuvers. CAS aircraft fly missions in direct support of the friendly ground forces when tactical aerial bombardment is needed and requested. Enemy anti-aircraft defenses are those that normally are associated with the Warsaw Pact countries and are comprised of both guns and surface-to-air missiles. Friendly air superiority over the battlefield is assumed so enemy aircraft are not a factor. CAS fighters are launched and attack in single-ship flights only and are limited to two weapons delivery passes on the target. Only one target is scheduled per sortie. Although these last few assumptions may seem restrictive, they do not degrade the study in its present form; a future user could easily extend the model to include the multi-aircraft, multi-target sortie. Ordnance available to the

fighter aircraft range from a 20 mm or 30 mm rapid-fire cannon, through free-fall high-explosive bombs and cluster bomb units, to laser guided or television guided stand-off weapons. Maintenance and other ground support resources are those that would be found with a normal tactical fighter squadron of twenty-four aircraft deployed to a forward operating base.

Weather Matrix (A)

A full description of the model used to derive the weather matrices employed in this study and the matrices themselves can be found in Chapter III. Briefly, the weather matrix is an n x n transition probability matrix, where n is the number of mutually exclusive weather states defined in the simulation. It reflects weather persistence as well as frequency of occurrence so that the effects of the persistence of bad or good weather can be studied. The elements of the matrix are the transition probabilities, p_{ij}. They indicate that if the weather is in state i, the probability of going to state j in the next time period is p_{ij} for $i = 1, \ldots, n$, $j = 1, \ldots, n$. Three different 10 x 10 weather matrices were used in this study. They were a winter matrix which reflects the worst weather conditions normally found in Europe, a summer matrix reflecting generally good weather conditions, and an identity matrix for holding the weather in a constant state during a computer run. For further details see Chapter III.

Initial Weather State (WST)

The initial weather state describes the weather conditions at the beginning of a simulation run.

Number of Sortie Requests (NUMB)

NUMB is the number of sortie requests per twenty-four hour period generated by the simulation. Any number can be used to reflect the intensity of the battle. In the example, the number of sortie requests was based on a sortie rate of 1.5 sorties per aircraft per day. This resulted in an average of 36 sorties requested every 24 hours with 75 percent occurring in the daylight hours of 0600--1800 and 25 percent at night. (Ref 58)

Number of Aircraft in Squadron

The number of each type of aircraft under study are input as AC1, AC2, AC3, etc., for the numbers of type 1, type 2, type 3, etc., aircraft in the squadron. Each type would be a variation of the basic aircraft due to the addition of electronic and/or armament gear, however the model is also amenable to comparing and contrasting aircraft types defined by criteria other than avionics packages. Other possible points of comparison would be single-seat versus multi-seat aircraft and aircraft equipped with extra, externally carried, fuel tanks to allow longer loiter time in the target area.

This investigation focused on two versions of the same fighter-bomber aircraft. One version, called Type 1, is the basic airplane with only those avionics systems required for accomplishing the basic CAS mission. Type 2 is the same aircraft equipped with increased electronic countermeasures and the avionics necessary to provide a stand-off weapons capability such as daytime television tracking, laser ranging and designation, and the armament, computers, and cockpit displays associated with these systems. The squadron simulated was composed of twenty-four aircraft and included various combinations of Type 1 and Type 2 aircraft.

Target Types (Sortie Types)

Target types are not direct inputs to the model, but they are used as independent variables in several of the inputs. In addition, sortie requests are designated by the type of enemy target that the mission is to be flown against. In the model, each target is assigned a number from 1 to n, where n is the total number of target types in the scenario. Sortie requests are then identified by these target numbers. It should be noted that the terms "target type" and "sortie type" are synonymous.

Target types are not only defined by the actual physical targets but also by the enemy defenses associated with them. For example, one target type may be defined as a bunker complex defended by small arms and 23 mm guns, and another may be a bunker complex defended by 57 mm guns. The user of the model may designate as many target types as are necessary to conduct his analysis.

In the hypothetical example six target types were used. They are the following:

Target Type (1) Troops in Contact defended by 23 mm guns.
(2) Troops in Contact defended by 57 mm guns.
(3) Tanks defended by 23 mm guns.
(4) Tanks defended by 57 mm guns.
(5) Artillery Sites defended by 23 mm guns.
(6) Artillery Sites defended by 57 mm guns.

The term "Troops in Contact" refers to a situation where opposing infantry units are engaged in close combat, where "close" can mean fifty to one-hundred meters apart. The importance of this close proximity of friendly troops to enemy troops will be explained presently. The combatants are assumed to be in the open or in shallow, temporary fortifications. The tanks are assumed to be the standard Soviet T-54 medium

tank which is common among the Warsaw Pact countries. Artillery Sites are bunkered and camouflaged long-range guns such as 100 mm and 130 mm pieces. The 23 mm antiaircraft gun is a multi-barreled rapid-firing weapon with optical tracking capability, and the 57 mm gun is a single-barreled piece with optical or radar tracking systems available. (Ref 32) (Ref 46:50)

Target Lifetimes

Associated with each target is a target lifetime which is the time in minutes that a target remains strikable. This time is measured from the time the sortie request enters the list of requested strikes. For example, enemy troops in the open are only going to remain in such a vulnerable position a fairly short time, and there would be no need to launch a sortie against them if that time had expired. If the analyst felt that these times were unimportant in his study, the times could be set at very large values and set equal for every target type. In the example problem, the lifetimes were chosen to be relatively short and varied among the target types. This was done to reflect the mobility envisioned for each target as well as to add realism to the scenario by simulating a rapidly changing battle situation. The lifetimes used for each target type were:

(1) 50 minutes.

(2) 60 minutes.

(3) 75 minutes.

(4) 90 minutes.

(5) 120 minutes.

(6) 180 minutes.

Aircraft Preferences (WXCD)

Each combination of weather state and sortie type (target type) is assigned a set of aircraft preferences. The size of the set of preferences depends on the number of aircraft types used in the study. These sets of preferences are lists of aircraft type numbers that indicate, in order, which type of aircraft is desired for a particular weather/sortie combination. If only one aircraft can be used for a mission, then only its number would be indicated in the preference list. (The reader is referred to Chapter II, Endogenous Event REQST, for an explanation of how this information is actually coded in the program.)

The aircraft preferences used to exercise the model for this paper were chosen on the basis of three factors. First, it was assumed that because of reliability considerations the stand-off weapons could not be used in sortie types 1 and 2 (Troops in Contact). This is because the close proximity of friendly troops to the enemy would preclude any type of delivery tactic other than manual release at low altitude directly over the enemy forces. Until the Close Air Support Missile (CASM), currently under development, becomes operational, this is a reasonable assumption. (Ref 46:25) The impact of this assumption is that there is little advantage in using the Type 2 aircraft against targets 1 and 2; therefore, Type 1 was preferred (because of lower cost) with Type 2 as a back-up if no Type 1 aircraft were available for the mission. Second, certain weather conditions prohibit the effective use of stand-off weapons. When this was the case aircraft Type 1 was selected with Type 2 as second choice except where attrition probabilities were very high. Third, where weather conditions permitted the employment of the stand-off weapons, they were utilized. In a few cases where attrition rates were

very high, it was reasoned that Type 1 aircraft would be too vulnerable, so only Type 2 were used.

The following table shows the aircraft preferences used in the simulation runs in this study. The entries in the table are the preferred types of aircraft; the number in parentheses is the second choice. Where no parentheses appear there is no second choice.

Sortie Number

Weather State		1	2	3	4	5	6
	2	1 (2)	1 (2)	1 (2)	1 (2)	1 (2)	1 (2)
	3	1 (2)	1 (2)	1 (2)	1 (2)	1 (2)	1 (2)
	4	1 (2)	1 (2)	1	1	1	1
	5	1 (2)	1 (2)	2 (1)	2 (1)	2 (1)	2 (1)
	6	1 (2)	1 (2)	2 (1)	2 (1)	2 (1)	2 (1)
	7	1 (2)	1 (2)	2	2	2	2
	8	1 (2)	1 (2)	2 (1)	2 (1)	2 (1)	2 (1)
	9	1 (2)	1 (2)	2 (1)	2 (1)	2 (1)	2 (1)
	10	1 (2)	1 (2)	2	2	2	2

Note that no sorties are launched in weather state 1 because of low visibility.

<u>Reaction Time (REAC)</u>

REAC is the time in minutes it takes to react to a sortie request, take off, and fly to the Forward Edge of the Battle Area (FEBA) where enemy area defenses begin. This time can be set at any value to reflect sortie request processing times, scramble times, distance from the base to the FEBA, and aircraft speed.

Forth minutes was used as the reaction time in the example. The forty minute time was based on five minutes of processing in the Tactical Air Support Center (TASC), fifteen minutes to scramble the alert aircraft, and twenty minutes to fly to the FEBA. It should be pointed

out here that once an aircraft becomes ready to fly, it is assumed to be loaded with ordnance suitable to all target types, refueled, and on alert status.

Target Attack Time (TARG)

The time it takes the strike aircraft to fly from the FEBA to the target and complete its attack is the target attack time. This is a completely arbitrary figure and can be utilized to reflect any situation within the operational capabilities of the aircraft being studied. Twenty minutes was used for this time throughout this analysis.

Return Time (RET)

Return time from the target area to the forward operating base was set at thirty minutes throughout the study.

Probability Aircraft Not Hit By Area Defenses (SVFB)

Enroute to the target each aircraft flies through an area of enemy air defenses which are not associated with an individual target. These defenses can be of any intensity the analyst chooses to simulate. The probabilities assigned depend on the aircraft type and the weather state, and they reflect the probabilities of a particular aircraft type, flying in a particular weather state, not being damaged by enemy ground-fire. These numbers are available from several sources. There are many studies and models in use which generate attrition probabilities for aircraft penetrating enemy airspace. Some are OPSTRA6: Effectiveness of a Three-Layer Defense Against an Optimally Allocated Offense, Stanford Research Institute, (Ref 25) TACOS C2, Tactical Air Defense Computer Operational Simulation, Braddock, Dunn, and McDonald, Inc., (Ref 16) and the AFATL P1127 Model, Air Force Armament Laboratory, (Ref 27)

In this analysis the two aircraft types were distinguished by different ECM capabilities -- Type 2 having a more advanced ECM system. The input matrix follows.

		Aircraft Type 1	Aircraft Type 2
Weather State	2	.980	.996
	3	.984	.996
	4	.988	.998
	5	.940	.992
	6	.960	.994
	7	.980	.996
	8	.904	.992
	9	.920	.994
	10	.940	.996

SVFB = P{A/C Not Hit By Area Defenses} = f(A/C Type, Wx State)

As always, weather state 1 is not included because aircraft are not launched in this weather condition.

Probability Aircraft Not Killed If Hit (DVFB)

This input is a measure of the vulnerability of each type of aircraft to enemy fire. The entries are probabilities of the aircraft not being downed if hit by fire from the area defenses. These numbers are available from vulnerability studies as well as the penetration models and studies mentioned above. Since it was presupposed that differing avionics packages would have no effect on vulnerability once the aircraft was hit by antiaircraft fire, this study used the same probability, 0.5, for each aircraft.

Probability FAC Available (FAC)

This input is the probability that a Forward Air Controller is available to direct the strike, and it is a function of the target type being struck. It is conceivable that in some situations FACs may not be able to control all the strikes requested by the ground commanders, and this may have a limiting influence on the number of successful sorties. In come cases targets may be struck without a FAC, but this seldom occurs in the close air support environment and never when friendly forces are close to the target. The probabilities for the example were chosen arbitrarily as follows:

Target Type	(1)	1.0
	(2)	1.0
	(3)	0.99
	(4)	0.97
	(5)	0.95
	(6)	0.95

$$FAC = P\{\text{FAC Available}\} = f(\text{Target Type})$$

Sortie Can Be Flown Without FAC (NFAC)

This input is simply an indicator, 1 for Yes and 0 for No, that the target can be attacked without a FAC. It depends on the target type and the aircraft type. The following data were used:

		Aircraft Type 1	Aircraft Type 2
Target Type	1	0	0
	2	0	0
	3	0	0
	4	1	1
	5	0	0
	6	1	1

$$NFAC = f(\text{A/C Type, Target Type})$$

Probability Aircraft Not Hit By Target Defenses (SVT)

For each aircraft type there are probabilities of not being hit by the target defenses. The probabilities depend on the target type being struck and the current weather state; they are single-pass probabilities. There are several good models available that generate this type of information. One is the FAIRPASS aircraft attrition model used by Air Force Studies and Analysis, Hq USAF (AF/SA) and another is the SIMFIND Models of Antiaircraft Gun Systems developed by the Institute for Defense Analysis, Washington, D.C. (Ref 60) Still another is the Antiaircraft Artillery Simulation Computer Program -- AFATL Program P001, developed at the Air Force Armament Laboratory, Eglin AFB, Florida. (Ref 53)

The input matrices used for this analysis follow:

SVT1 = P{ A/C 1 Not Hit By Target Defenses } = f(Target Type, Wx State)

Sortie Type

		1	2	3	4	5	6
	2	.280	.520	.290	.524	.287	.522
	3	.273	.510	.283	.514	.280	.512
	4	.267	.500	.277	.504	.273	.502
Weather State	5	.667	.780	.767	.840	.763	.838
	6	.500	.640	.600	.720	.597	.718
	7	.333	.540	.433	.600	.430	.598
	8	.850	.846	.950	.906	.947	.904
	9	.840	.832	.940	.882	.937	.880
	10	.820	.790	.800	.850	.767	.848

SVT2 = P{ A/C 2 Not Hit By Target Defenses } = f(Target Type, Wx State)

		Sortie Type					
		1	2	3	4	5	6
Weather State	2	.280	.520	.300	.564	.297	.562
	3	.273	.510	.300	.554	.297	.552
	4	.267	.500	.293	.550	.290	.548
	5	.667	.780	.833	.890	.830	.888
	6	.500	.640	.817	.878	.813	.876
	7	.333	.540	.800	.870	.797	.868
	8	.850	.846	.970	.974	.976	.972
	9	.840	.832	.967	.970	.963	.968
	10	.820	.790	.950	.960	.947	.958

Probability Aircraft Not Killed If Hit By Target Defenses (DVT)

As with the area defenses, this input is a measure of vulnerability; however, DVT depends on target type. An aircraft hit by a large caliber weapon is more likely to be shot down than one hit by a smaller projectile. This data is available from the studies mentioned above and others.

The numbers used were:

		DVT
Target Type	1	.7
	2	.5
	3	.7
	4	.5
	5	.7
	6	.5

DVT = P{ A/C Not Killed Given A/C Hit By Target Defenses } = f(Target Type)

As the model is currently constructed, no distinction is made between

aircraft types in this input. The model could, however, easily be modified to reflect differences in vulnerability among aircraft types.

Probability Aircraft Kills Target (PKT)

The probability that a target is destroyed on a single pass depends on the aircraft type, target type, and the weather state. The probabilities are predicated on the assumption that the attacker uses the best available ordnance and delivery tactics which conditions permit. One good source of this information for specific aircraft is the Sabre Armor Study at Air Force Studies and Analysis (AF/SAGF). (Ref 40)

As a general rule, in estimating the probabilities to use in the example. It was assumed that stand-off weapons could not be used against target types 1 and 2 and in weather states 2, 3, and 4. Their effectiveness was presumed to be slightly degraded in weather states 7 and 10. The input matrices follow:

PKT1 = P{ A/C 1 Kills The Target} = f(Target Type, Wx State)

Sortie Type

		1	2	3	4	5	6
	2	.81	.80	.44	.43	.74	.72
	3	.83	.82	.42	.41	.72	.70
	4	.75	.74	.39	.38	.69	.67
Weather State	5	.90	.89	.45	.45	.60	.60
	6	.92	.91	.44	.43	.57	.56
	7	.89	.88	.42	.41	.54	.53
	8	.95	.94	.50	.50	.62	.62
	9	.93	.92	.49	.48	.59	.58
	10	.91	.90	.47	.46	.56	.55

mean repair times of the individual avionics systems in each aircraft. They were MTBA1 = 1.9902898 hours and MTBA2 = 2.633799 hours.

Mean Time To Repair Battle Damage (MTB)

When aircraft sustain battle damage, but are able to return to base, they must be repaired before being scheduled for another sortie. MTB gives the mean time to repair this battle damage for each aircraft type.

MTB1 = 12 hours and MTB2 = 18 hours were used as estimates in the example. The difference was due to the complex avionics that may be damaged in aircraft type 2. MTB estimates were obtained from Major Tetmeyer. (Ref 58)

Turnaround Times (RFL)

If aircraft return from a mission undamaged and with no avionics failures, then they can be refueled and reloaded and placed on alert status immediately. The fact that an aircraft can undergo some kind of maintenance failure other than avionics was not germane to the problem being studied and was therefore not considered. However, one could include such a factor without much difficulty.

The times to refuel and reload each type of aircraft are the turn-around times RFL. Those used were RFL1 = 30 minutes and RFL2 = 45 minutes. The difference here is due to the more advanced armament that is loaded on aircraft 2. Again, these estimates were provided by Major Tetmeyer. (Ref 58)

Conclusion

In conclusion, it once again should be emphasized that the simulation model is very flexible in the types of input data it will accept. The

PKT2 = P A/C 2 Kills The Target = f(Target Type, Wx State)

Weather State		Sortie Type 1	2	3	4	5	6
	2	.81	.80	.50	.49	.80	.78
	3	.83	.82	.47	.46	.77	.75
	4	.75	.74	.41	.40	.71	.69
	5	.90	.89	.75	.75	.80	.80
	6	.92	.91	.74	.74	.79	.79
	7	.89	.88	.70	.69	.75	.75
	8	.95	.94	.79	.79	.82	.82
	9	.93	.92	.78	.78	.82	.81
	10	.91	.90	.76	.75	.80	.80

Mean Sorties Between Avionics Failures (MTBF)

MTBF is the mean number of sorties flown between avionics failures for each aircraft type. A detailed description of how this data is used can be found in Chapter II, Subroutine AVION. MTBF depends, of course, on the type of avionics installed in each aircraft type and, thus, provides a point of comparison between the two aircraft types in this study.

Estimates for MTBF1 and MTBF2, as well as all other maintenance input data, were suggested by Major D. C. Tetmeyer of the Air Force Human Resources Laboratory, Wright-Patterson AFB. (Ref 58) His modeling work is an excellent source for this type of data and should be considered by future users of this model. The estimates input in this study were MTBF1 = 6.2869515 and MTBF2 = 3.9867591.

Mean Avionics Repair Time (MTBA)

MTBA is the mean time to repair failed avionics systems for each aircraft. The estimates used were based on a weighted average of the

actual numbers cited in this chapter are those that were used in the hypothetical example used to demonstrate the model. This example in no way implies that a future user of the model is restricted to numbers of this type.

V. ANALYSIS OF COMPUTER-GENERATED TIME-SERIES DATA

Introduction

In this chapter the authors address many of the problems typically encountered in computer simulations and discuss their relevance to the present study. Specifically, this chapter is concerned with (1) the steady-state nature of the simulation, (2) the effects of initial conditions upon the simulation, and (3) the autocorrelation process inherent in the simulation.

The Steady-State Nature of the Simulation

For most simulations one is interested in determining the steady-state or expected value performance of the system. Quite often the steady-state performance of a system is used as its primary measure of merit. Because this has been a popular approach with many past studies, the authors begin by examining the steady-state nature of the close air support simulation.

The first question which must be asked is, "What constitutes a steady-state condition for our system?" Analysts typically think of such a condition as one in which most of the system parameters begin to settle down from initial fluctuations to stable values. Unfortunately, this type of steady-state condition exists only in particular types of systems such as certain inventory processes, manufacturing processes, or communication networks. For the close air support simulation, quite the reverse is true. Under the present set of assumptions most system parameters fluctuate continuously with no general tendency towards stability. Three such parameters are presented for a typical run of the simulation model in figures 7, 8, and 9. The first two figures represent the availability of aircraft at a particular time (midnight) during each

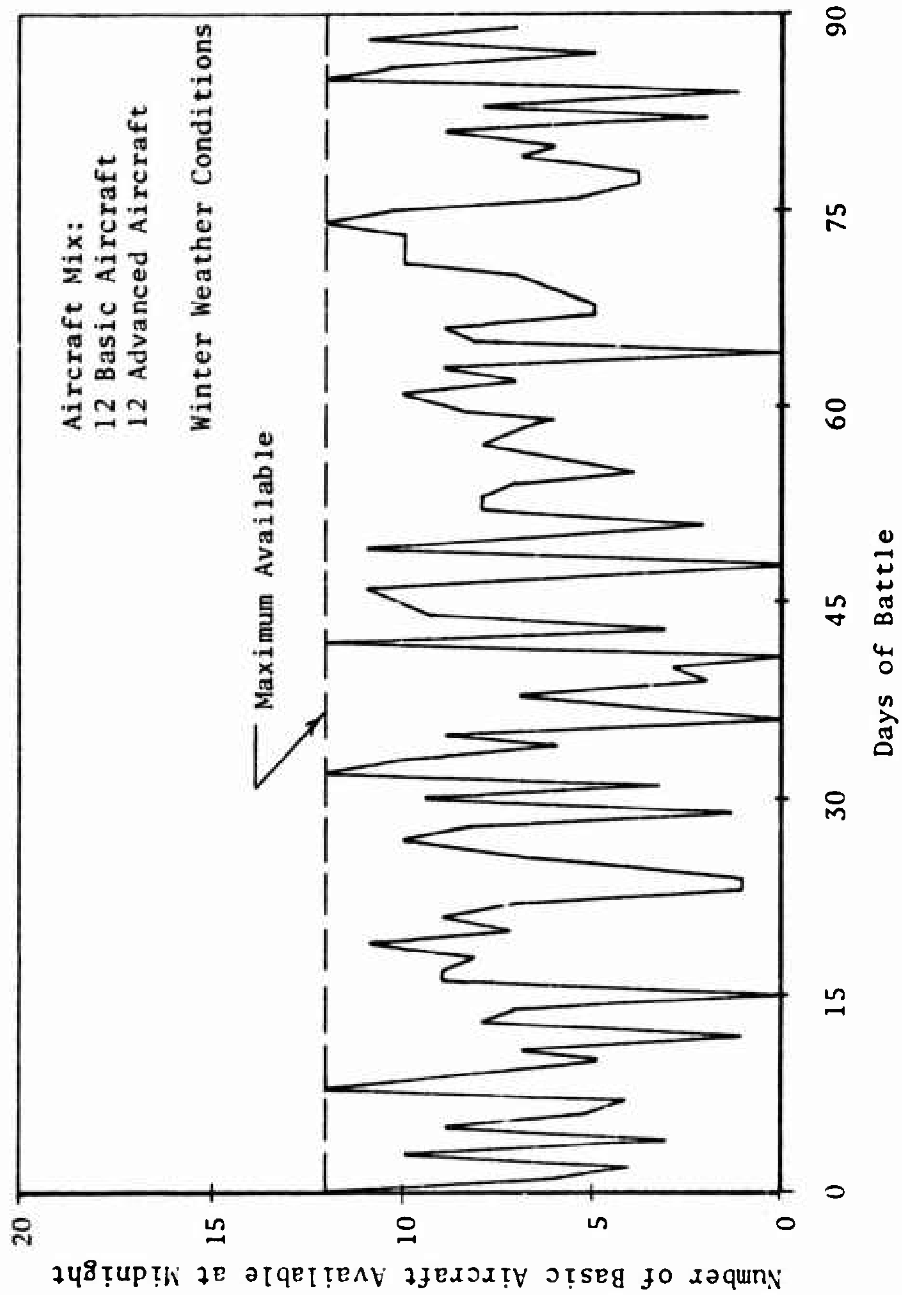


Figure 7 Number of Basic Aircraft Available at Midnight

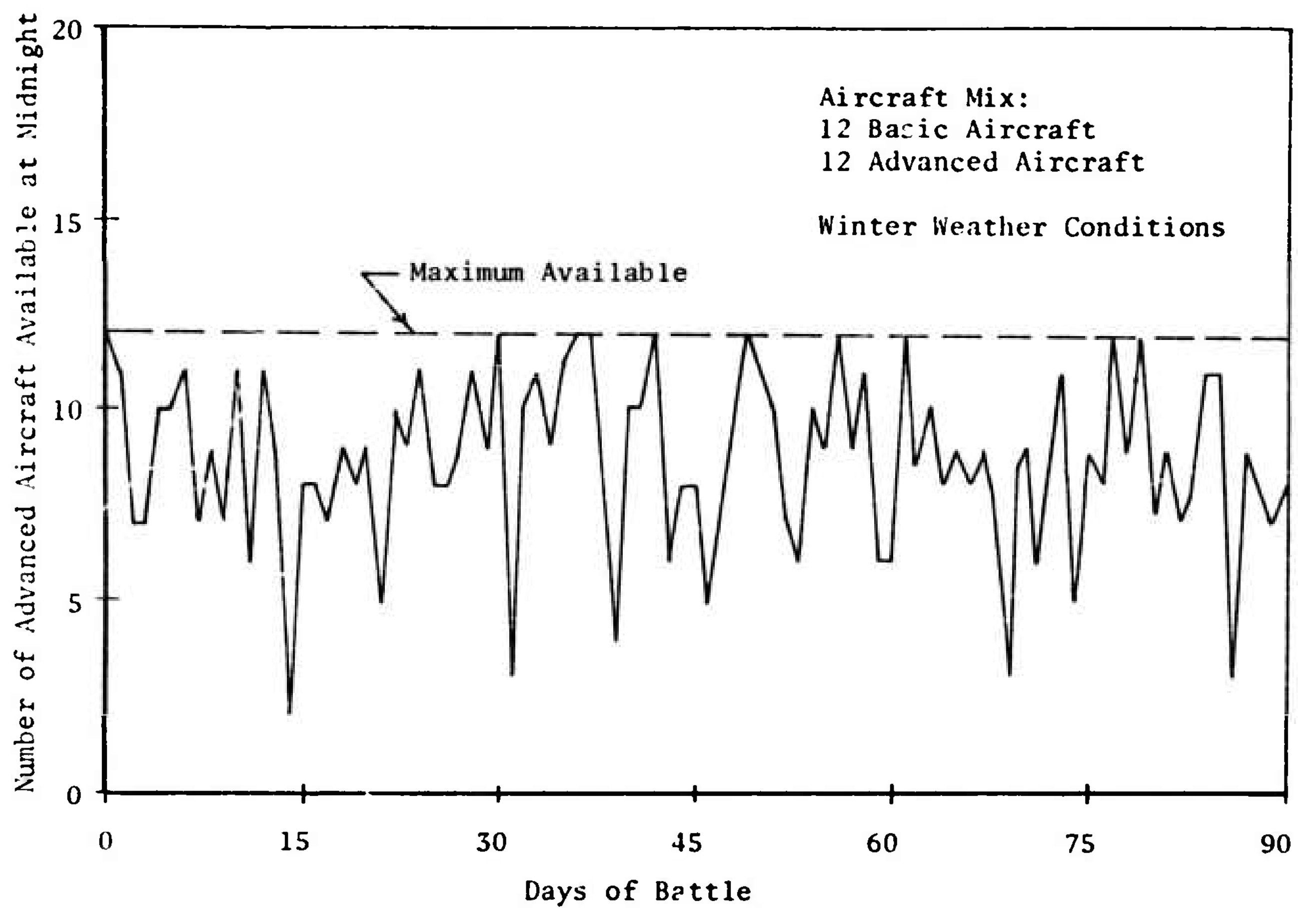


Figure 8 Number of Advanced Aircraft Available at Midnight

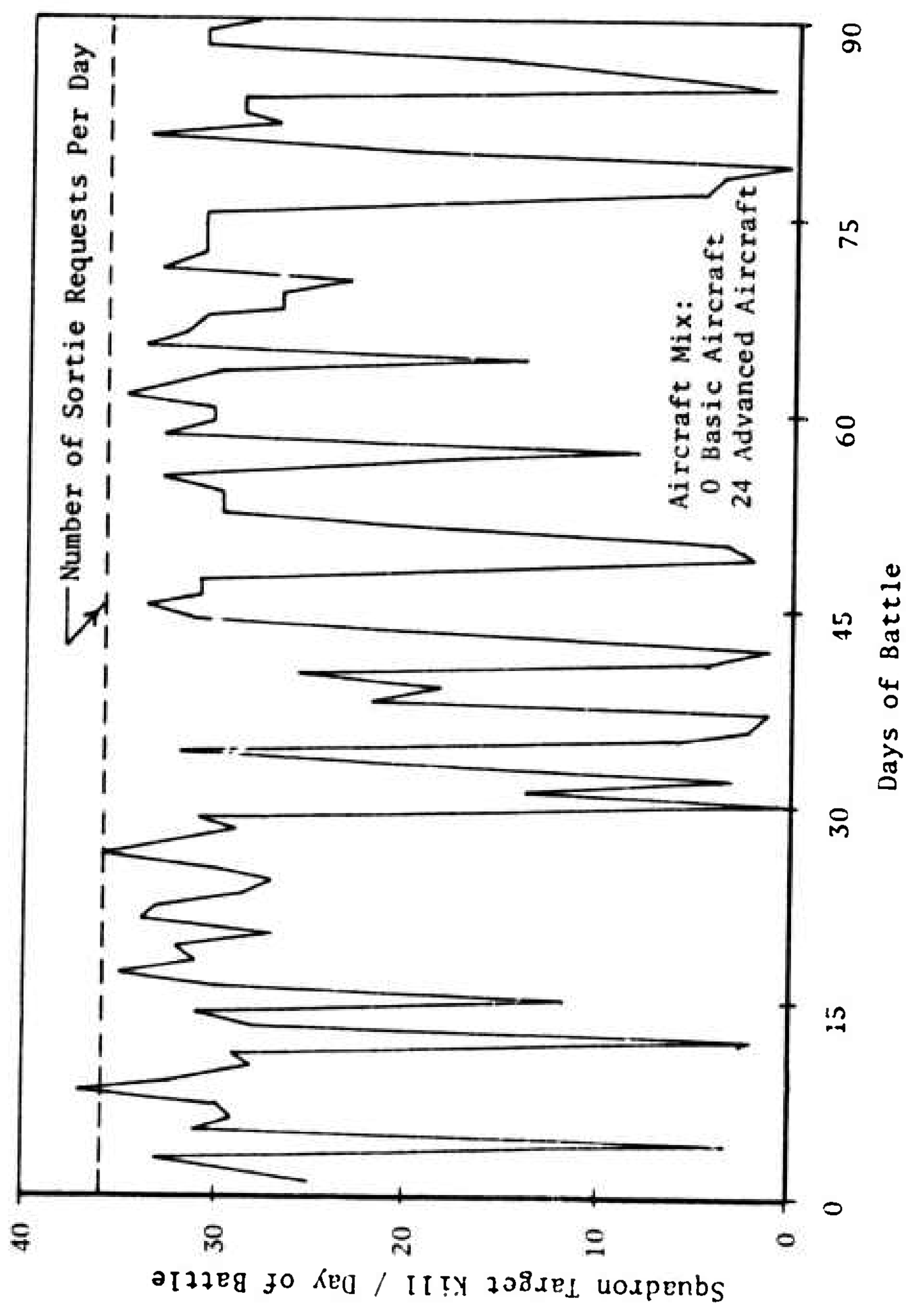


Figure 9 Squadron Target Kill Versus Days of Battle

simulated day of battle. The last figure represents the daily number of targets destroyed by the close air support squadron. As will be discussed later, the primary cause of instability in these parameters is the extreme fluctuation of weather conditions. Compare figure 9 to figure 10 where we have the unrealistic case of constant weather conditions. As suggested by the relative stability in figure 10, weather conditions play an important role in this simulation.

In Reference 10, Conway states that

> ... equilibrium is a property of the state probability distribution of the system and not of the particular values of the state of the system which might be observed in a given run.

Thus, we might gain insight into the system being simulated by observing the state probability distribution of the system's important parameters. One parameter of particular interest is the number of targets destroyed per day by the squadron. This variable was highlighted in chapter II as being closely related to the mission effectiveness of the close air support squadron. Figure 11 shows the relative frequency distribution of this random variable for winter weather conditions. The data presented in this figure are based on 270 days of simulated battle where the squadron was given 36 target opportunities (sortie requests) per day. The shape of this distribution suggests that the number of targets killed per day is bimodal in nature. Possible reasons for this distribution shape again refer back to the influence of weather conditions on the operation of the squadron. Since weather conditions change in the simulation model every hour, it is difficult to describe an "average" weather condition for an entire day. However, it was found that days experiencing relatively high percentages on bad weather corresponded closely to low numbers of targets killed and that days

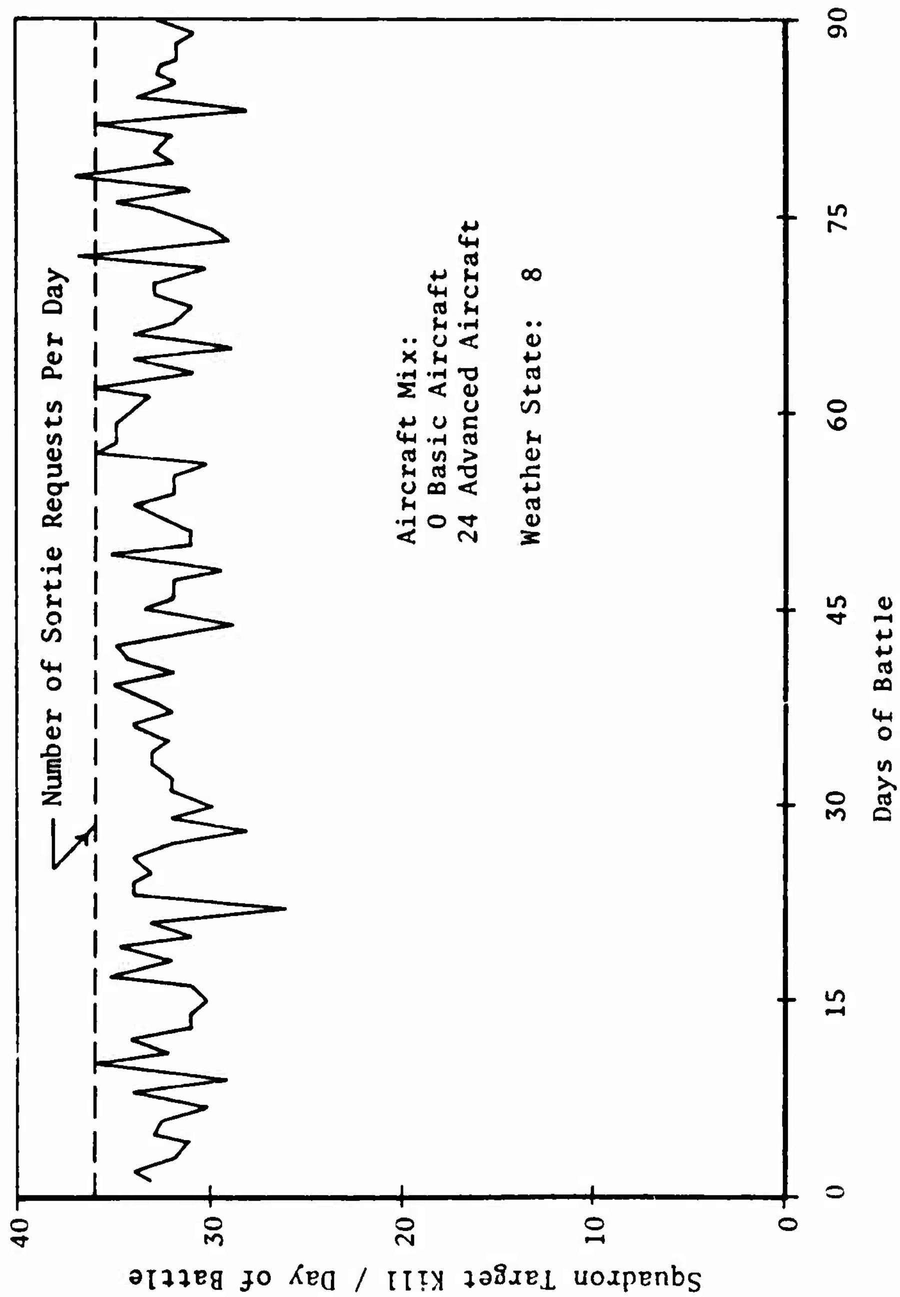


Figure 10 Squadron Target Kill for Weather State 8

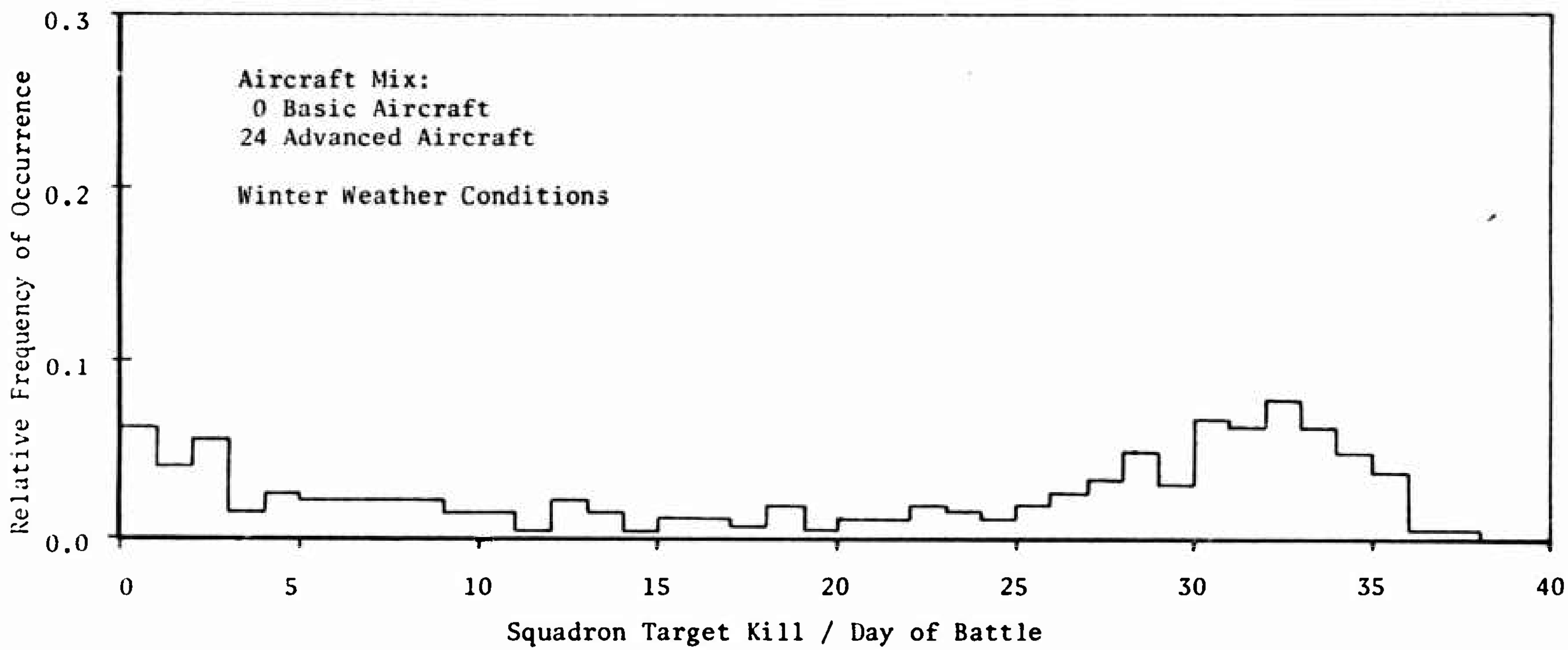


Figure 11 Relative Frequency Distribution for Squadron Target Kill During Winter

experiencing relatively low percentages of bad weather corresponded closely to high numbers of targets killed. The close correlation of the number of targets killed per day to daily "average" weather conditions suggests that weather conditions act as a binary-type switch for squadron effectiveness.

To explore this relationship further, a series of cases were simulated under constant weather conditions. This was accomplished by starting the simulation in the desired weather state and replacing the weather state transition probability matrix by an identity matrix. Figures 12, 13, and 14 show that for constant weather conditions the number of targets killed per day is approximately normally distributed with a mean value being a function of the weather conditions used for each case. Comparing these figures to figure 11, it is not unreasonable to assume that the average distribution displayed in figure 11 is the result of summing the individual normal distributions according to the frequency of each weather state.

During the summer months a slightly different situation exists as shown by the relative frequency distribution presented in figure 15. For this case, the constancy of good weather results in a more unimodal distribution. As compared to figure 11, the lower mode of the distribution has vanished because of the relatively infrequent occurrence of bad weather during the summer. As will be shown later, the particular shape of this distribution affects our confidence in the steady-state or expected-value estimates for the number of targets killed per day by the squadron.

Where does all of this leave the analyst who is attempting to determine whether or not steady-state conditions have been reached?

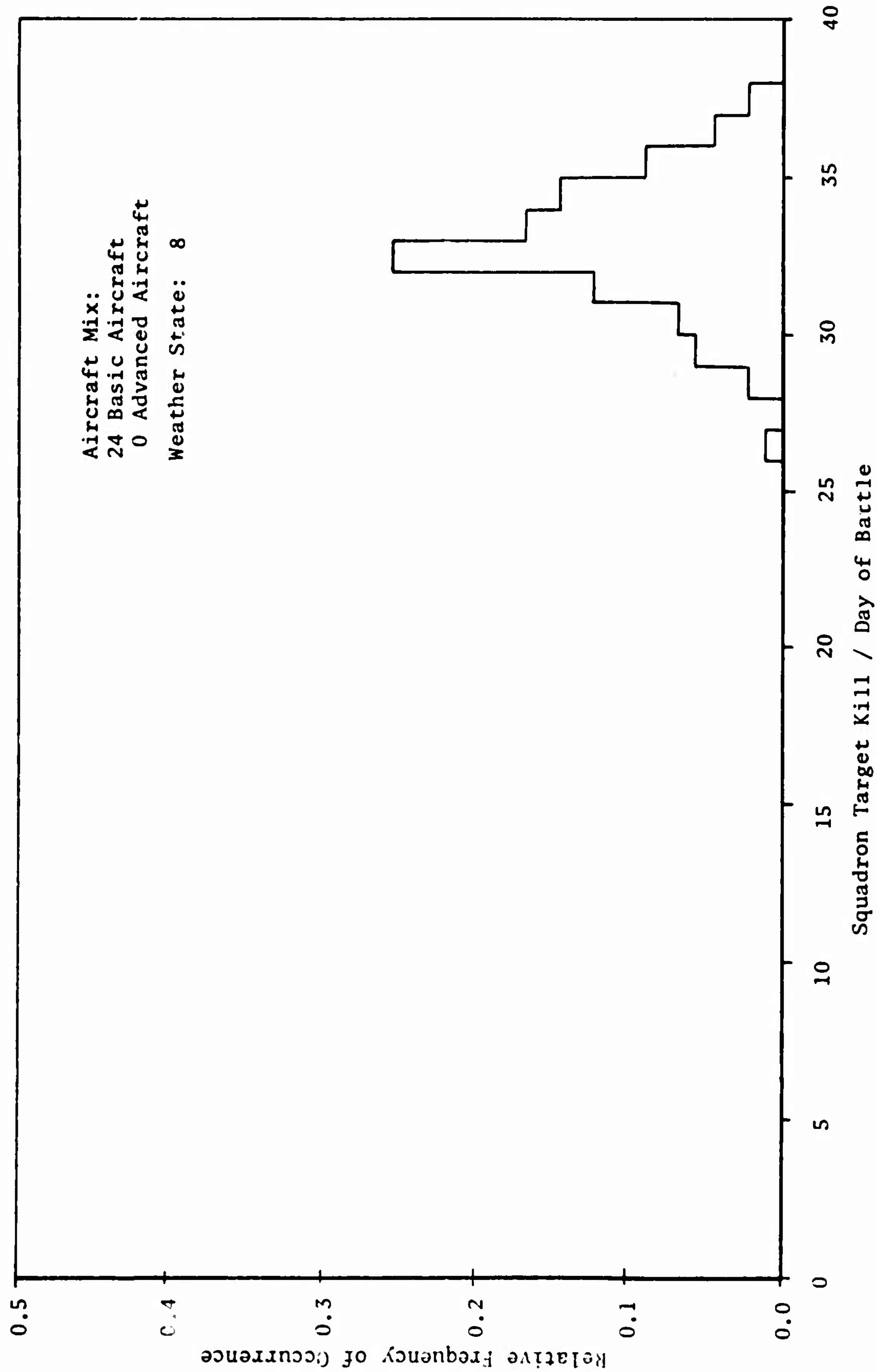


Figure 12 Relative Frequency Distribution for Squadron Target Kill in Weather State 8

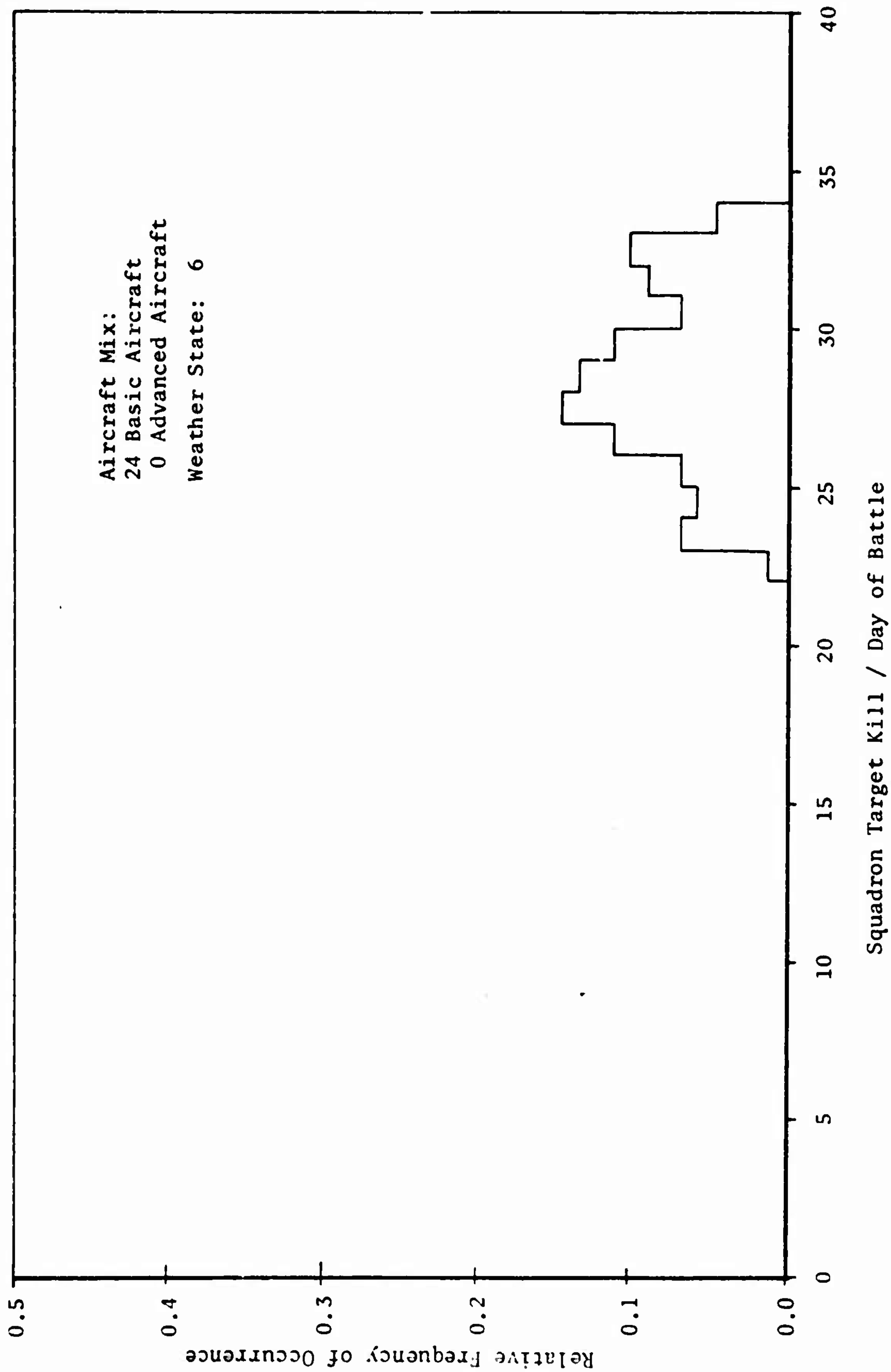


Figure 13 Relative Frequency Distribution for Squadron Target Kill in Weather State 6

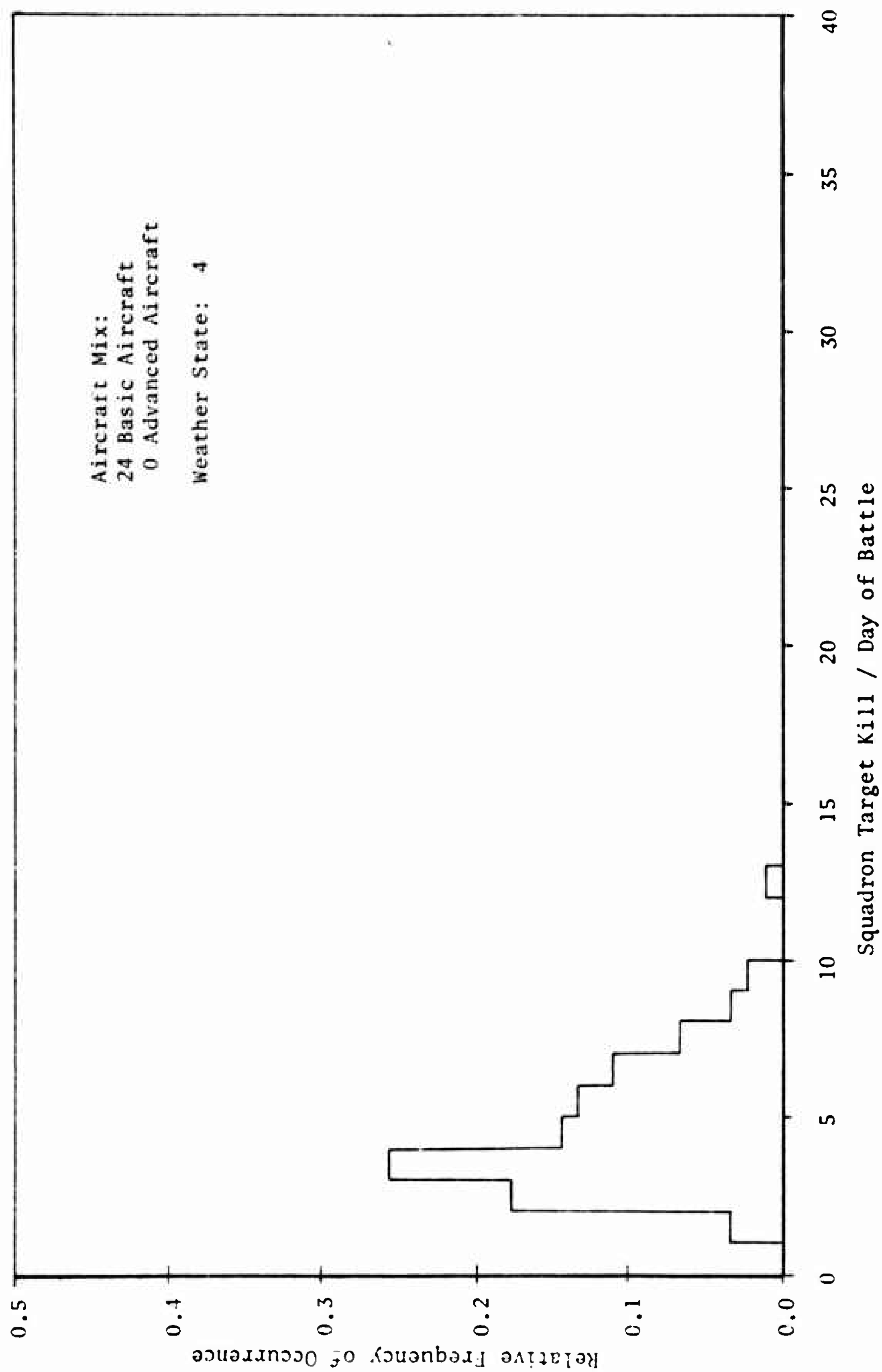


Figure 14 Relative Frequency Distribution for Squadron Target Kill in Weather State 4

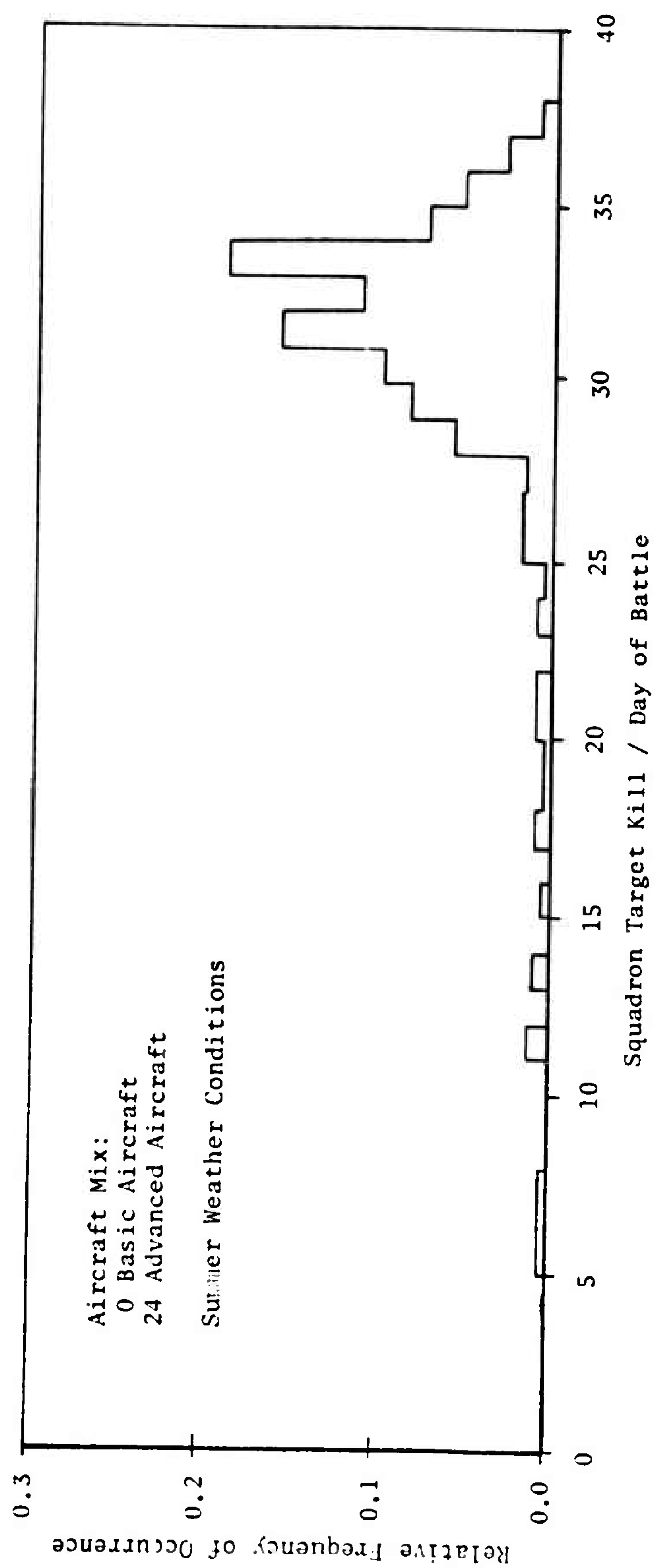


Figure 15 Relative Frequency Distribution for Squadron Target Kill During Summer

In Reference 10, Conway goes on to state that

> ... it is also important to recognize that equilibrium is a limiting condition which may be approached but never actually attained. This means that there is no single point in the execution of a simulation experiment, beyond which the system is in equilibrium. The difference between the temporal and limiting distribution presumably decreases with time and one seeks a point beyond which he is willing to neglect the error that is made by considering the system to be in equilibrium.

The search for this point leads many analysts to consider confidence intervals for the estimated parameters. By constructing a confidence interval for the mean of the parameter of interest, the analyst may determine the sample record length necessary to bring his conclusions within acceptable margins of error.

Although the predominant use of confidence intervals is with random variables assumed to belong to normal or Gaussian populations, the central limit theorem allows one to apply the general results to non-normal populations so long as certain requirements are met. (Ref 33:196)

Specifically, the statistic

$$\frac{\sqrt{n-1}\,(\overline{X} - \mu)}{S}$$

where n is the sample size, S^2 is the sample variance of the data, and $\overline{X}$ is the sample mean of the data, has a limiting distribution which is normal with zero mean and a variance of one. This fact allows one to construct the following approximate confidence interval for system parameters.

$$\left[\overline{X} - \frac{S}{\sqrt{n-1}} Z_{\alpha/2}\right] = \mu = \left[\overline{X} + \frac{S}{\sqrt{n-1}} Z_{\alpha/2}\right]$$

where $Z_{\alpha/2}$ is the value such that the integral of the standard normal density function from $Z_{\alpha/2}$ to ∞ equals $\alpha/2$. One can now assert with the probability of $(1 - \alpha)$ that the parameter mean, μ, lies in the interval given above.

Applying the above relation to the number of targets destroyed per day, a series of confidence intervals were generated for different sample sizes. These results which were taken from a typical simulation run are presented in Table 1. Again, these results are associated with winter weather data.

Sample Size (Days)	Mean (Target Kill/Day)	95% Confidence Interval Lower Bound	Upper Bound
30	27.60000	24.64375	30.55625
60	27.05000	24.83848	29.26152
90	24.76667	22.73410	26.79923
120	23.93333	22.08702	25.77965
150	22.31333	20.50779	24.11888
180	21.41667	19.70901	23.12433
210	22.23610	20.67355	23.80264
240	21.87500	20.40056	23.34944
270	22.13704	20.75859	23.51548

Table 1 Confidence Intervals for Target Kill/Day

As the data in Table 1 illustrates, convergence of the confidence interval is extremely slow. In fact, the ninefold increase in sample size from 30 to 270 has reduced the confidence interval by only about 53%. Primary reason for the slow speed of convergence is the bimodal nature of the random variable when winter weather data is used. To decrease the confidence interval further implies an additional cost to the analyst in terms of computer time. For this study a sample size of 270 days was considered to be a reasonable tradeoff between accuracy of estimates and computer running time.

Because of the extreme fluctuation in the number of targets killed per day during the winter, this weather condition was assumed to represent a worst case situation in terms of the size of the above

confidence interval. Corresponding sample sizes used with summer weather data produced confidence intervals approximately 35% as large as those produced with winter weather data. This result was expected since it was found that the number of targets killed per day in the summer had a unimodal distribution. To be consistent, a sample size of 270 days was used for both winter and summer simulation cases even though the resulting confidence in these estimates varied from case to case. Future users of the simulation model may wish to vary the number of simulation runs for different types of situations so as to produce a more uniform degree of confidence in their answers and results.

It should be noted that up to this point in the analysis the authors have not considered the effects of autocorrelation on the size of confidence intervals. To neglect the effect of autocorrelation when it is significantly present in the data results in a considerable underestimation of the size of the confidence interval. Very briefly, if one assumes that the daily observations of the number of targets killed contain no amount of autocorrelation, he implies that he believes the performance of the close air support squadron on one day to be completely unrelated to its performance on adjacent days. From an intuitive viewpoint, it is difficult to imagine that the operation of the close air support squadron today would not affect in some manner the operation of the squadron tomorrow. Thus, it is instructive to investigate the amount of autocorrelation, or interdependence, contained in the series of daily observations of target kill. One technique reported by Fishman can be built into the simulation computer program and used to adjust the size of the computed confidence intervals. (Ref 19) Because the adjustment made for autocorrelation is rather time consuming to the analyst, it is

wise to make a preliminary check of the time series data to see whether or not a significant amount of autocorrelation exists. And though Fishman's technique was not incorporated into the present computer model because of time limitations on this study, a brief investigation was made to determine the amount of autocorrelation present in the time series data for the number of targets killed per day. A later section of this chapter highlights the results of this investigation.

One final comment on the subject of steady-state conditions can be made with regard to averaged or cumulative statistics. Emshoff and Sisson point out that they have found a simple method for determining when steady-state conditions exist. (Ref 13:192)

> ... There are no fixed rules for determining when steady-state conditions can be assumed. A simple method we have found to be useful involves examining a sequence of observations from the run. If the number of observations in which the output is greater than the average to a given point is about the same as the number in which it is less, then steady-state conditions are likely to exist. Another method is to compute a moving average of the output and to assume steady-state when the average no longer changes significantly over time.

Unfortunately, the first method relies on the assumption that the observations are distributed symmetrically. If the mean and median of the observations are not coincident, the method of comparing the number of observations above and below the average fails. Such is the case for the number of targets killed per day in the close air support simulation. The bimodal distribution of this random variate resulted in approximately 57.4% of the observations lying above the mean even after steady-state conditions were assumed to exist at 270 observations.

The second method which computes a moving average is viewed with equal suspicion. As shown in figure 16, the average value of targets killed per aircraft loss shows a general tendency to settle down somewhere after the seventieth day of war. The data presented here represents

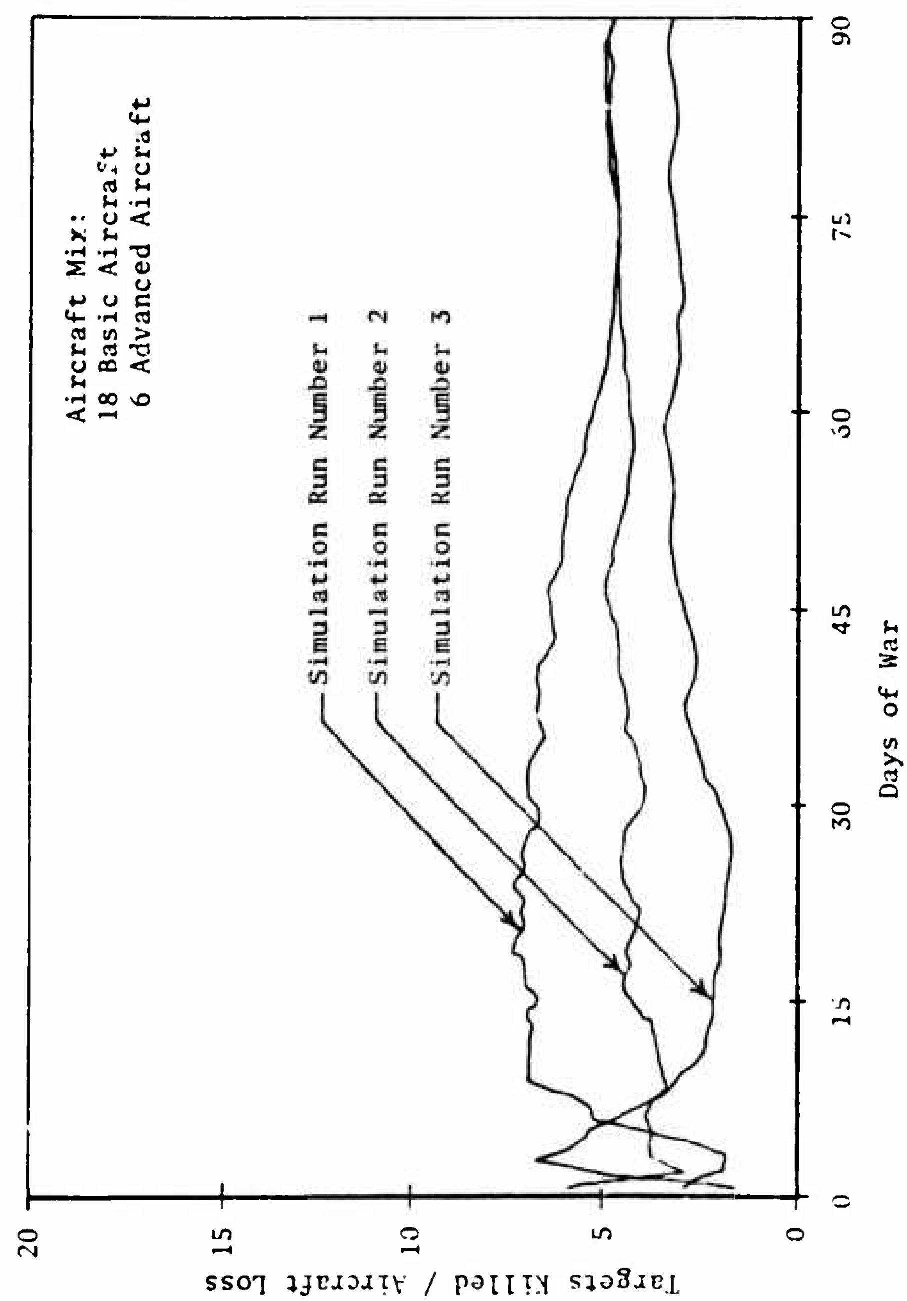


Figure 16 Cumulative Number of Targets Killed Per Aircraft Loss

three runs of the simulation for identical squadrons, yet one could not state with very much confidence that the average for any one of these 90-day runs represented the true steady-state average for the simulation. Therefore, it was concluded that neither of the methods suggested by Emshoff and Sisson should be adopted without preliminary evidence supporting their usefulness. For the present study neither method was pursued further.

The Effects of Initial Conditions on the Simulation

Another major concern with the study of both transient and steady-state results of simulations is the influence of initial conditions. For many simulations, initial conditions can severely bias system performance and lead to unjustified conclusions. Concern for this phenomenon has led many authors to suggest possible ways of removing unwanted transient results so as to eliminate the bias created by initial conditions. According to Emshoff and Sisson there are several methods of accounting for this bias. (Ref 13:191)

(1) Start the simulation in a priori steady-state conditions.

(2) Use long simulation runs so the data from the transient period is insignificant relative to data in the steady-state.

(3) Introduce a non-recording period to get the simulation into steady-state conditions before measurements are taken.

Before considering the above methods, the authors will first examine the initial conditions of the close air support simulation. To begin with, the simulation is started under the assumption that all aircraft assigned to the squadron are initially on ready status. As the simulation proceeds, the number of aircraft on ready status becomes a random variate since aircraft from the squadron are either engaged in

operations or are completing various maintenance and repair cycles. Referring to figures 7 and 8, the number of aircraft available at a specified time of day (midnight) fluctuates considerably with no apparent distinction between transient and steady-state periods. As stated previously, most of the fluctuation is related to changes in weather conditions. As a result of such data, it was assumed that the effects of initial conditions were insignificant beyond the first few days of the simulation. So as not to leave the reader with the impression that the authors feel the initial transient behavior of the simulation is itself insignificant, a later chapter presents a further investigation of this period under adverse weather conditions. The present discussion is only with regards to our examination of steady-state behavior of the systems.

The relatively small influence of initial conditions beyond the first few days of the simulation makes it unworthwhile to either start the simulation in a priori steady-state conditions or bother with an initial non-recording period for the simulation. Instead, the effects of initial conditions were assumed by the authors to be insignificant for the length of simulation periods used in gathering steady-state information about the close air support operations.

Once the appropriate sample size has been estimated for the study, the analyst may take either of two different approaches setting up his computer runs. The first method is to make a series of short or intermediate length computer runs using a variety of different initial conditions and different random number strings. A second method recommended by Conway is to merely continue a single computer run for a long period of time. (Ref 10:57) In this manner it is assumed that the

"replication" is achieved by increasing the length of the simulation period. The primary reason for using the single computer run approach is that it has only one transient period compared to the multiple transient periods associated with the multiple short computer runs. However, since the close air support simulation was considered to have relatively short transient periods, this argument did not carry much weight. Finally, the authors concluded that because of the nature of this simulation either method provided a satisfactory approach.

Autocorrelation

In this section the authors expand on the topic of autocorrelation which was introduced in an earlier section of this chapter. As mentioned previously, the question of whether or not the time series data from a simulation is autocorrelated first arises during the process of constructing confidence intervals. If autocorrelation is present in the data, one must replace the estimate of the variance of the mean by

$$\hat{\sigma}_\mu^2 = \frac{\hat{\sigma}_x^2}{N} \left[1 + 2 \sum_{s=1}^{N-1} \left(1 - \frac{s}{N}\right) \rho(s) \right]$$

where $$\rho(s) = \frac{E[(X_t - \mu)(X_{t+s} - \mu)]}{\hat{\sigma}_x^2}$$ (Ref 20)

As can be seen from the above equation, autocorrelation implies that $\rho(s)$ will be significantly different from zero for some values of s. This, in turn, implies a modification of $\hat{\sigma}_\mu^2$ from the original estimate given by $\hat{\sigma}_\mu^2 = (\hat{\sigma}_x^2 /N)$. Emshoff and Sisson point out that correlation can be artificially introduced into certain types of simulations and used to actually reduce the variance of the estimated mean. (Ref 13:198) However, the authors are interested here in only the autocorrelation arising naturally from the simulated system.

One may deal with autocorrelated data in a variety of ways beginning with two simple methods outlined by Emshoff and Sisson. (Ref 13:199) (1) Estimate precisely the autocorrelation function and include its effects in the estimation of the mean and variance of state variables. (2) Group the time series data into blocks of consecutive observations such that each block represents an independent observation. Then use standard statistical estimation methods.

Although both methods use the same estimate for the mean, there is a difference of opinion as to which method is more efficient. On the one hand, the use of an estimated autocorrelation function always provides a minimum variance estimate for the mean. (Ref 13:200) On the other hand, reported tests of both methods suggest that the computer time required to estimate the autocorrelation function is so great that it overwhelms the advantage gained by using the autocorrelation function in estimating the variance of the mean. (Ref 28) Thus, Emshoff and Sisson conclude that it is nearly impossible to recommend either method without knowing the particular characteristics of the individual simulation.

Before examining the close air support simulation, let's introduce yet another approach outlined by Fishman. (Ref 20) This author introduces the concept of "correlation time" of a process. In a sense, the correlation time, together with the observation interval (sample size), defines the number of equivalent independent observations contained in the autocorrelated data. The following equations show how the correlation time is related to the variance of the mean.

(1) Define the estimated autocorrelation function as

$$\hat{R}(T) = \hat{r}(T)/\hat{r}(0)$$

where

$$\hat{r}(T) = \frac{1}{N-T} \sum_{t-1}^{N-T} (X_t - \overline{X})(X_{t+T} - \overline{X}) .$$

(2) The estimated variance of the mean becomes

$$\hat{V} = \frac{\hat{r}(0)}{N} \left[1 + 2 \sum_{T-1}^{M} (1 - \frac{T}{M})\hat{R}(T) \right] , M < N-1$$

(3) The correlation time is now defined as

$$\hat{T}* = (N\hat{V})/2\hat{r}(0)$$

where the number of equivalent independent observations is

$$\hat{N}* = N/2\hat{T}* = \hat{r}(0)/\hat{V}$$

As Fishman shows, the number of lags (M) chosen for the estimate can be less than N-1 when the sample record length (N) is sufficiently large.

To show how this applies to the close air support simulation, a series of estimates were made using data from typical runs of the simulation model. The random variable chosen was again the number of targets killed per day by the squadron. Figure 17 shows the average value of $\hat{R}(T)$ from three independent runs of the same simulation case. For these computations a sample size of 90 days was used along with a value of 30 for M. As can be seen, the amount of autocorrelation in the data is reduced considerably after a lag of about three days. Since the number of targets killed per day has been shown to be closely related to weather conditions, the data in figure 17 might infer something about the persistency of weather conditions. Specifically, the authors suggest that the autocorrelation displayed in figure 17

reflects the number of days one would expect general weather conditions to remain constant.

The number of equivalent independent observations was found to be $\hat{N}^* = 51.25$ days which implies a correlation time of $\hat{T}^* = 0.878$ days. Returning to the previous estimates of the confidence intervals associated with the mean number of targets destroyed per day, one can now see the effect of accounting for autocorrelation. The confidence interval presented in Table 1 for a sample size of 90 days was $(\overline{22.73410,26.79923})$ based on the assumption of no autocorrelation. A more accurate estimate of this same confidence interval is $(\overline{21.71142,27.82192})$ using the estimated autocorrelation function. Thus, one can see that the previous estimates assuming no autocorrelation understated the length of the confidence interval by about one-third. Furthermore, the value of T* for this example shows that including the effects of autocorrelation in the estimate of the variance is roughly equivalent to blocking the data into two-day periods.

The above estimates used in calculating the adjusted confidence interval should be viewed as very rough. The number of observations used to generate these estimates was only 270 compared to 16,000 observations used in similar calculations for an example problem presented in Fishman's paper. (Ref 20) And, for lack of time available to pursue this topic, no further investigations were made regarding autocorrelation in the close air support simulation. It is recommended, however, that future studies of the close air support problem should not only be concerned with the effect of autocorrelation on the size of the confidence intervals, but should also use tools such as the autocorrelation function to explain the dynamic characteristics of the close air

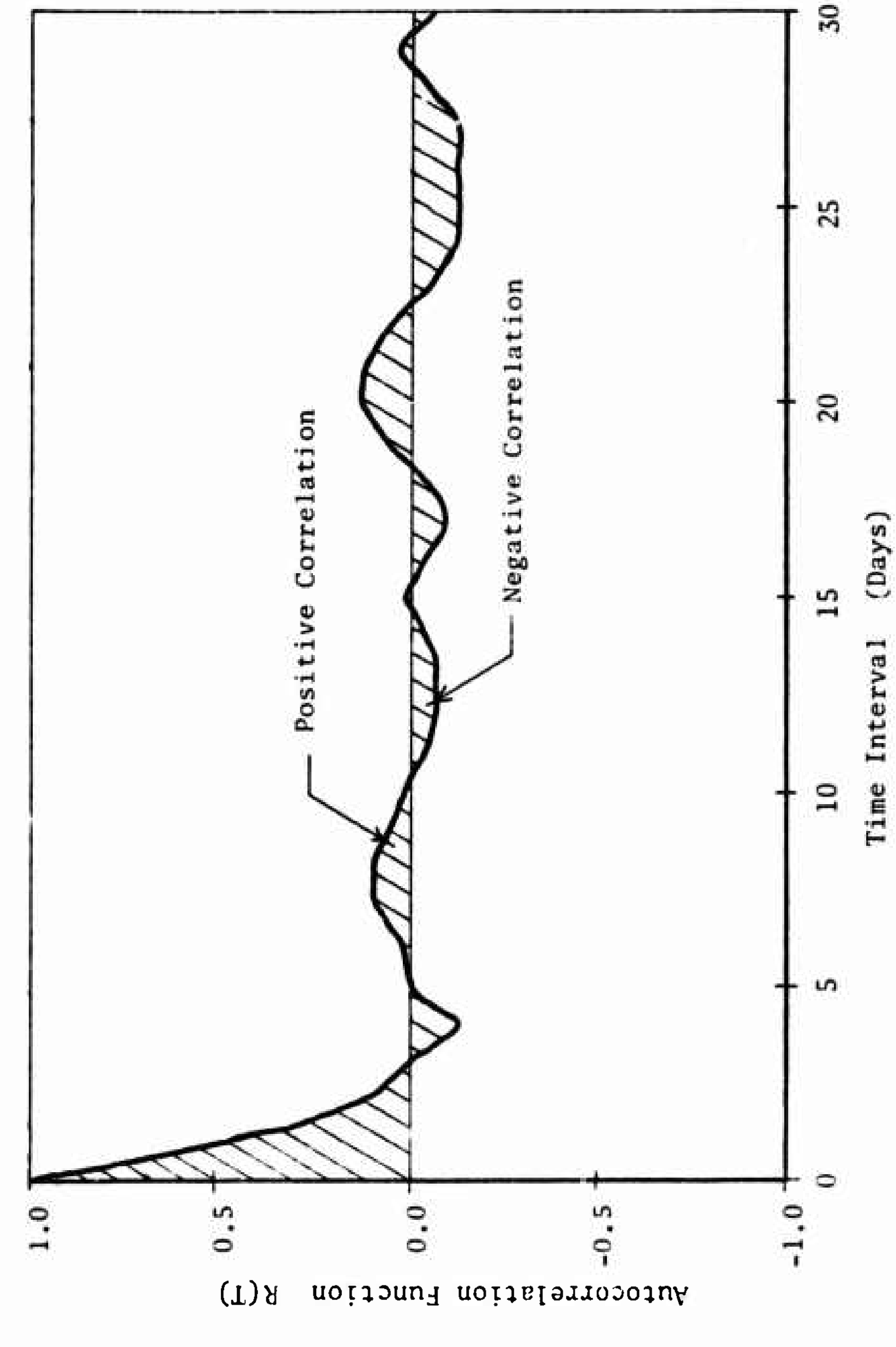


Figure 17 Estimated Autocorrelation Function for the Squadron Target Kill During Winter

support operation. The related subject of spectral analysis shows similar promise as an explanatory tool for future studies. Spectral analysis, a technique which investigates time series data in the frequency domain rather than in the time domain, is gaining publicity in the field of simulation studies since it is closely related to the autocorrelation function presented above. Two excellent introductions to the theory and application of spectral analysis are provided by Fishman in References 21 and 22.

VI. RESULTS OF HYPOTHETICAL EXAMPLE

In this chapter the authors present results of an analysis of the hypothetical example introduced in chapter IV. The analysis presented represents approximately two months of work performed after completion of the simulation model. The objectives of this analysis were:

(1) To study the effects of weather and avionic equipment variations on the operation of a close air support squadron,

(2) to study possible approaches to the problem of selecting an optimum mix of two types of fighter-bomber aircraft in a close air support squadron,

(3) to perform sensitivity analyses with several of the variables included in the simulation model, and

(4) to suggest possible extensions and uses of the model.

In this example, the authors considered two types of fighter-bomber aircraft assigned to the close air support mission role. The first type of aircraft was assumed to be equipped with only those armament and electronic components necessary to perform the elementary close air support functions. This aircraft is referred to as type 1, or the basic, aircraft in this study. The second type of aircraft was assumed to be identical with the first type except that it possessed additional avionic equipment which gave the aircraft an increased ECM capability and a capacity to launch and guide stand-off weapons such as the Maverick or laser-guided bombs. This second type of aircraft was referred to as type 2, or the advanced, aircraft in this study.

Obviously, one would expect the advanced aircraft to cost more and to be more effective in the close air support role. But, is the increased cost justified? In addition, is it possible to maximize

some measure of performance or effectiveness by using a mix of the two types of aircraft in the squadron? To answer these questions one must begin to define the available alternatives in terms of their "costs" and "benefits". Fisher elaborates on this topic by presenting the two responsibilities which must be fulfilled. (Ref 18:48)

> ... The decisions or choice to be analyzed must be clarified either by delineating the range of alternatives to be compared or, equivalently and more easily, by delineating the common component of all acceptable alternatives - that is, by specifying the "givens."
>
> ... A comprehensive accounting of all important differences, specified and unspecified, that will result from making one decision or choice rather than another, must be developed and presented to the decisionmaker. These differences should not only be identified, but wherever feasible measured and if possible evaluated.

Time limitations of this study forced the authors to limit the range of alternatives considered. It has already been mentioned that only two types of aircraft were used in this study. Obviously, future studies may wish to include a wider and more comprehensive range of variations in aircraft and on-board equipment. Other aspects of the problem which were fixed include:

(1) The target/defense scenario (except for a brief sensitivity analysis performed on area and target defenses),

(2) sortie lengths (flight-times of various segments of each sortie),

(3) weapon loads for each type of aircraft,

(4) mean failure rates for avionic equipment aboard each type of aircraft,

(5) mean repair times for avionic equipment failures and battle damage in both types of aircraft,

(6) number of aircraft assigned per sortie (one),

(7) number of targets assigned per sortie (one),

(8) number of target passes allowed for each sortie (two),

(9) number of sortie requests per day (except for a brief examination of the effect of changes in this number on the average number of sorties flown per day per aircraft),

(10) scheduling preferences for aircraft type (except for one unrestricted case examined for the advanced aircraft), and

(11) aircraft tactics (optimum tactics were assumed for each type of aircraft).

Although the above items were treated as constants throughout the present work, the authors do not wish to imply that any of them are insignificant to the problem. Each of these aspects of the problem could well be the subject of future studies related to close air support.

Two remaining variables considered to be the main point of interest in this paper are:

(1) Mix of aircraft in the squadron (five different mixes were considered), and

(2) general weather conditions (summer and winter).

In addition to an analysis of the above factors, study time permitted brief investigations into the following areas:

(1) Sortie rate,

(2) target/aircraft scheduling preferences,

(3) area defense attrition,

(4) target defense attrition, and

(5) effectiveness of ordnance.

Sortie Rate Analysis

Sortie rate, as defined in this paper, represents the average number of sorties flown per day by each aircraft in the squadron. This

rate, in turn, affects the entire operation of the forward airbase through the areas of maintenance personnel and facility requirements, inventory levels of spare parts and equipment, and POL requirements. Although the present simulation model does not consider the above areas in detail, the authors were still interested in determining a reasonable sortie rate f use in the squadron. Since sortie requests are specified in the simulation model rather than actual sorties, we were interested in finding out how the actual sortie rate varied with the number of sortie requests per day. Figure 18 shows this relationship for both aircraft types and for a range of sortie requests per day from 10 to 40. These results are based on single 90-day simulation runs using winter weather data. As can be seen, the advanced aircraft squadron achieves a slightly higher ratio of sorties flown per sortie request. This is because the scheduling preference codes allow this aircraft to fly more target/weather opportunities than the basic aircraft.

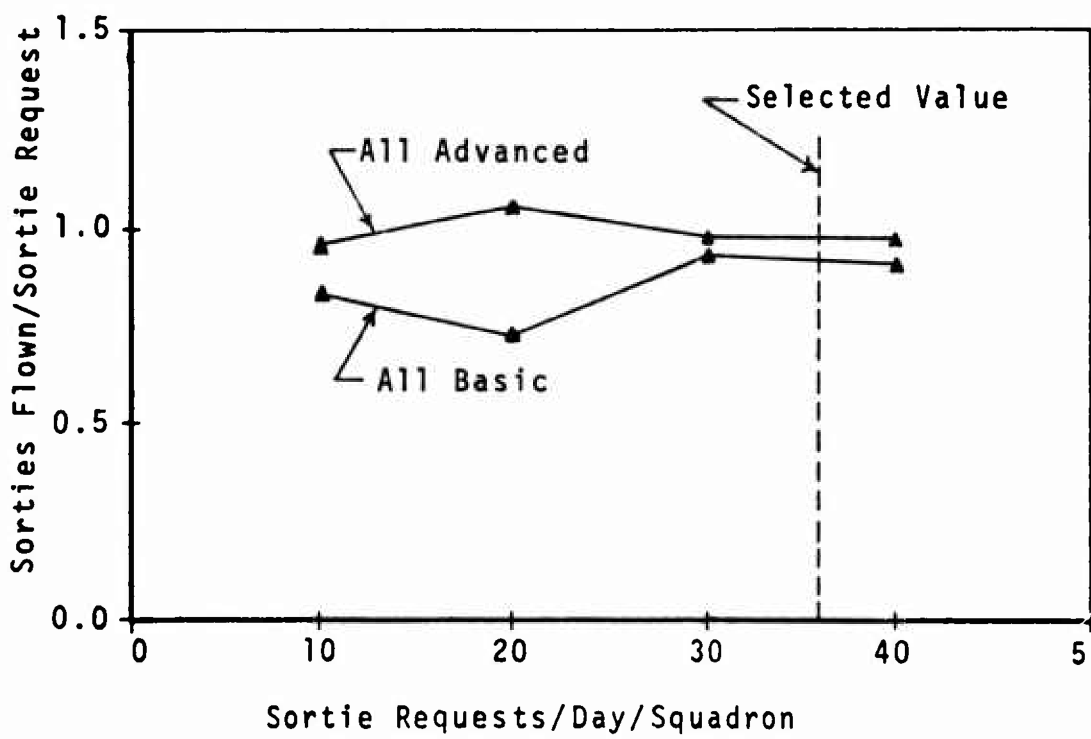


Figure 18 Relationship of Sorties Flown to Sorties Requested

The values presented in Figure 18 should be viewed as rough since they were based on only 90 days of simulated battle. However, the authors felt that it was reasonable to assume that the ratio of sorties flown per sortie request fell in the neighborhood of 1.0. Assuming this value to be true, we used a value of 36 sortie requests per day throughout the remainder of the study. A value of 36 sortie requests per day per squadron would then result in a sortie rate of about 1.5 sorties per day per aircraft which is a reasonable value to expect for a close air support operation.

Obviously, a ratio of one sortie flown per sortie request does not imply that every sortie flown is successful. Weather influences this ratio considerably and the amount of bad weather during the winter forces this ratio downwards. When aircraft are grounded due to bad weather conditions, sorties are not flown and often the associated targets are never struck. During periods of good weather, upwards to 55 sorties are flown per day by the squadron which results in a temporary sortie rate of over 2.0. On the average, however, the sortie rate is approximately 1.5.

As mentioned before, the simulation model does not presently consider personnel, facility, and inventory requirements at the forward airbase. Thus, the sortie rate used in the present study reflects a perfect maintenance system. If realistic queueing and supply limitations were considered in the model, the sortie rate would undoubtedly be lower because of occasional shortages of facilities, personnel and spare equipment.

Later in the analysis, several simulation runs were checked to see how the ratio of sorties flown per sortie request varied with

aircraft mix and general weather conditions. Figure 19 shows these relationships.

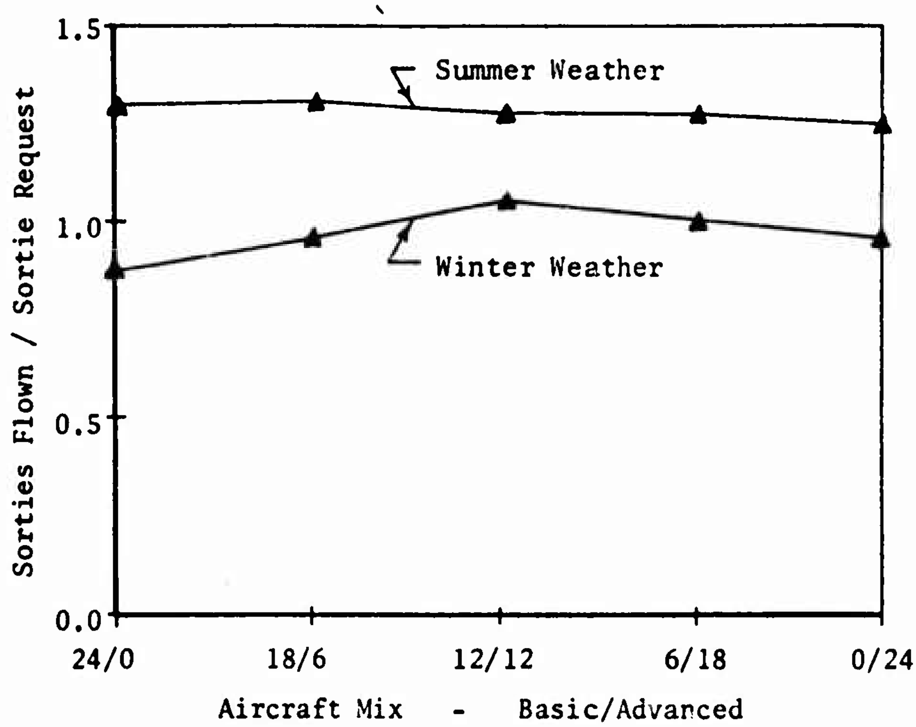


Figure 19 Sorties Flown/Sortie Request Versus Aircraft Mix

As expected, the better weather conditions during the summer allow more sorties to be scheduled against the average of 36 sortie requests per day. During the winter it appears as if the mixed squadron of 12 basic and 12 advanced aircraft allow the most number of sorties to be scheduled. Possible reasons for this fact again go back to the scheduling preferences used in the simulation model. Both types of aircraft are denied certain weather/target opportunities. A squadron which contains all of the same type of aircraft must simply forego certain opportunities to schedule sorties. A mixed squadron, on the other hand, allows overlapped coverage of all weather/target opportunities which results in a higher number of scheduled sorties.

Target Kill Rate Analysis

As mentioned in chapter II, target kill is used in this study as the basic measurement of squadron effectiveness. To show how this measure varies with general weather conditions and aircraft mix, a series of 30 simulation runs were made. Three 90-day battles were simulated for each of the five aircraft mixes and two general weather conditions. Data presented in Figure 20 represent the average number of targets killed by the squadron per day of battle (based on a total of 270 days). As described earlier in chapter V, the 270-day period was selected because this period of time produced acceptable steady-state estimates for this study and not because 270 days represented a logical duration of battle.

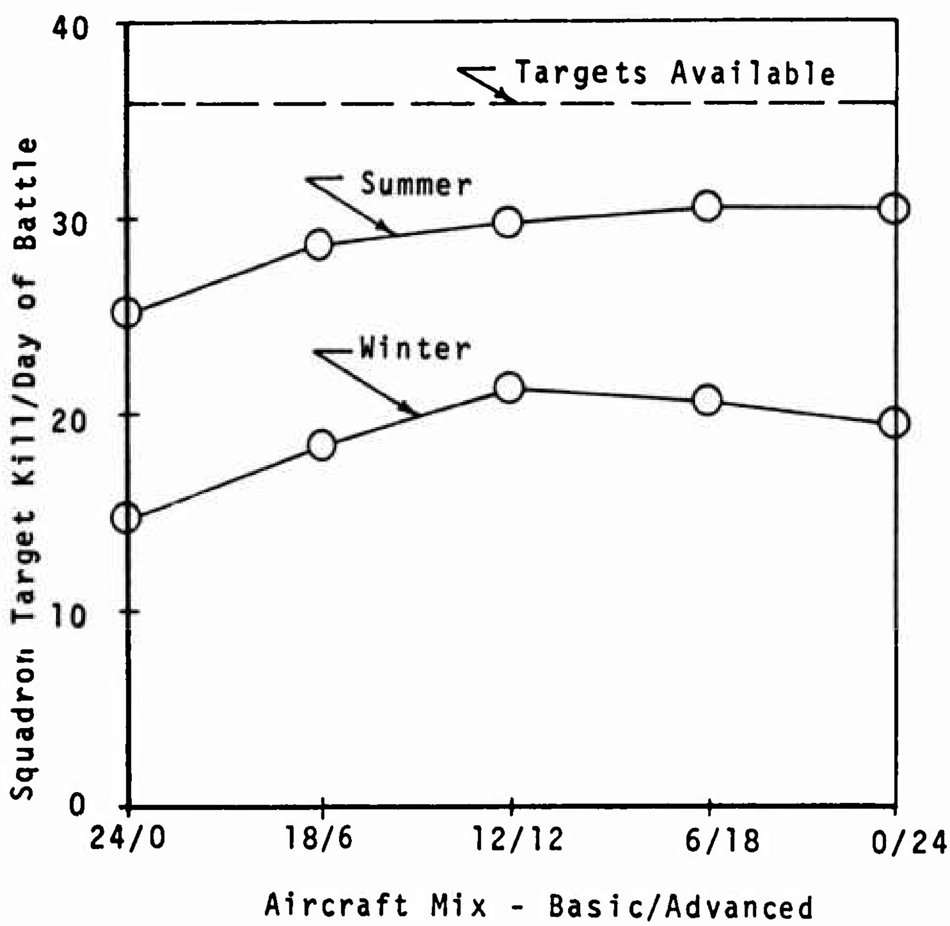


Figure 20 Squadron Target Kill for Various Aircraft Mixes

Three trends are noticeable from the data in Figure 20. First, there is a decrease in the number of targets killed per day as one moves from summer to winter weather conditions. This decrease is evident throughout the range of aircraft mixes and implies that even "all-weather" aircraft have reduced effectiveness in bad weather. Secondly, the number of targets killed per day in winter weather conditions is maximum for a mix of 12 basic aircraft and 12 advanced aircraft. This result can again be attributed to the scheduling restrictions discussed with reference to squadron sortie rates in the last section. The 12/12 mix simply allows an overlapping coverage of target/weather opportunities. The effect is not as apparent in summer weather conditions because better weather conditions result in fewer scheduling restrictions. Finally, the increased survivability and single pass target kill probability of the advanced aircraft has not produced a striking increase in the number of targets killed per day by those squadrons containing relatively high percentages of advanced aircraft. This reflects that fact that target kill potential is a function of many parameters. Weather conditions and scheduling restrictions influence squadron performance just as much as aircraft survivability and single pass target kill probability. As will be seen later, however, there does exist a striking difference in the attrition rates of friendly aircraft for the various aircraft mixes. This factor, coupled with the number of targets killed per day, provides better insight into the problem of optimizing the mix of aircraft within the squadron.

It was mentioned earlier in chapter V that the number of targets killed per day tends to have a bimodal distribution during the winter months. During the summer months, the constancy of good weather conditions results in a more unimodal distribution centered about the

mean. On the other hand, the mean value of targets killed per day in the winter occurs relatively infrequently because it lies between the two modes of the distribution. This implies that winter weather acts almost like a binary switch for squadron effectiveness. If weather conditions are either reasonable or good, the system operates in the higher mode: if the weather conditions are bad, the system operates in the lower mode. Because this is a definite problem for the squadron, many analysts are concerned over how long bad weather conditions might be expected to persist. To see how each of the five aircraft mixes recovered from periods of bad weather, a series of seventy-five 10-day battles were simulated with each mix being used in fifteen of these runs. Each simulation was started out in weather state 1 where it was assumed that bad weather conditions force the grounding of all aircraft. Figure 21 shows the recovery rate of each aircraft mix (based on an average of fifteen runs) in terms of the number of targets killed per day.

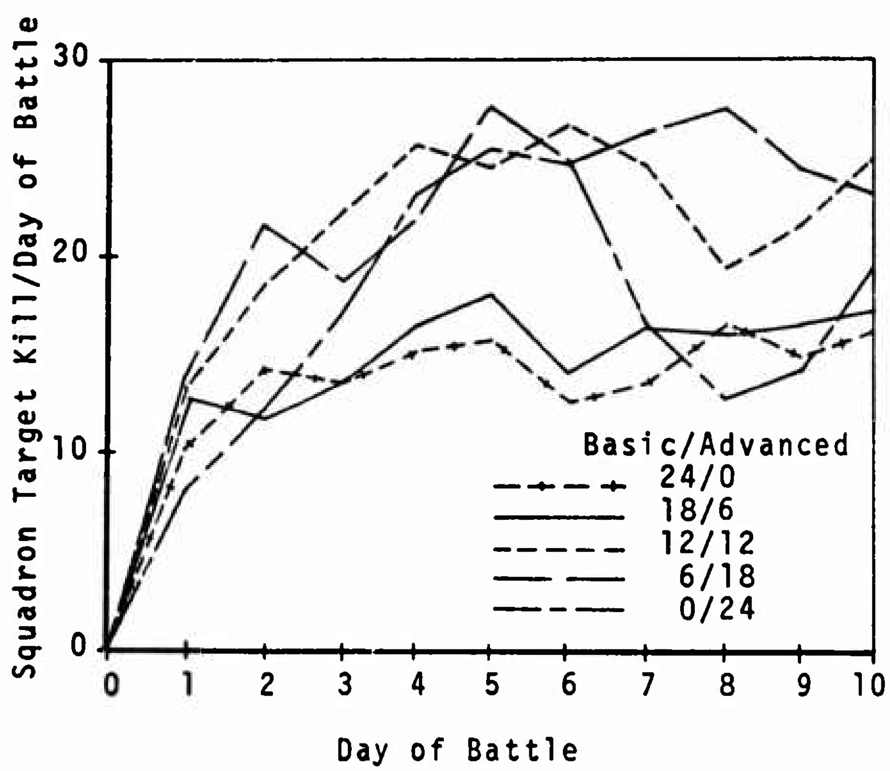


Figure 21 Recovery of Squadron Target Kill from a Bad Weather State

As can be seen from Figure 21, each of the aircraft mixes has approximately recovered to steady-state values by the third day of the battle. This result supports the suggestion made in chapter V that general weather conditions would be expected to persist no more than about three days. (See the discussion of the autocorrelation function and Figure 17 presented in chapter V.) Since study time permitted only a limited number of observations of this phenomena for each aircraft mix, it is suggested that our results should be viewed as only rough indications of weather persistency and that future studies analyze this aspect of the problem in greater detail.

Aircraft Loss Rate

The presence of enemy defenses implies that a certain number of friendly aircraft will be lost during the course of any close air support engagement. But, just how high is this loss rate? To answer this question, the simulation model was programmed to keep an account of the number of each type of aircraft lost to enemy defenses during the simulation runs. Figure 22 shows the expected daily loss rate for each of the five aircraft mixes and two general weather conditions. These loss rates coincide with the target kill rates presented in Figure 20. Data in Figure 22 shows that substantially fewer numbers of aircraft are lost per day as we begin to place all advanced aircraft in the squadron. The principle reason for the lower loss rate of the advanced aircraft is its standoff weapon capability which increases the aircraft's survivability against target defenses. Figure 22 also shows that the aircraft loss rates are essentially the same for both summer and winter weather conditions even though the target kill rates vary considerably between these two seasons.

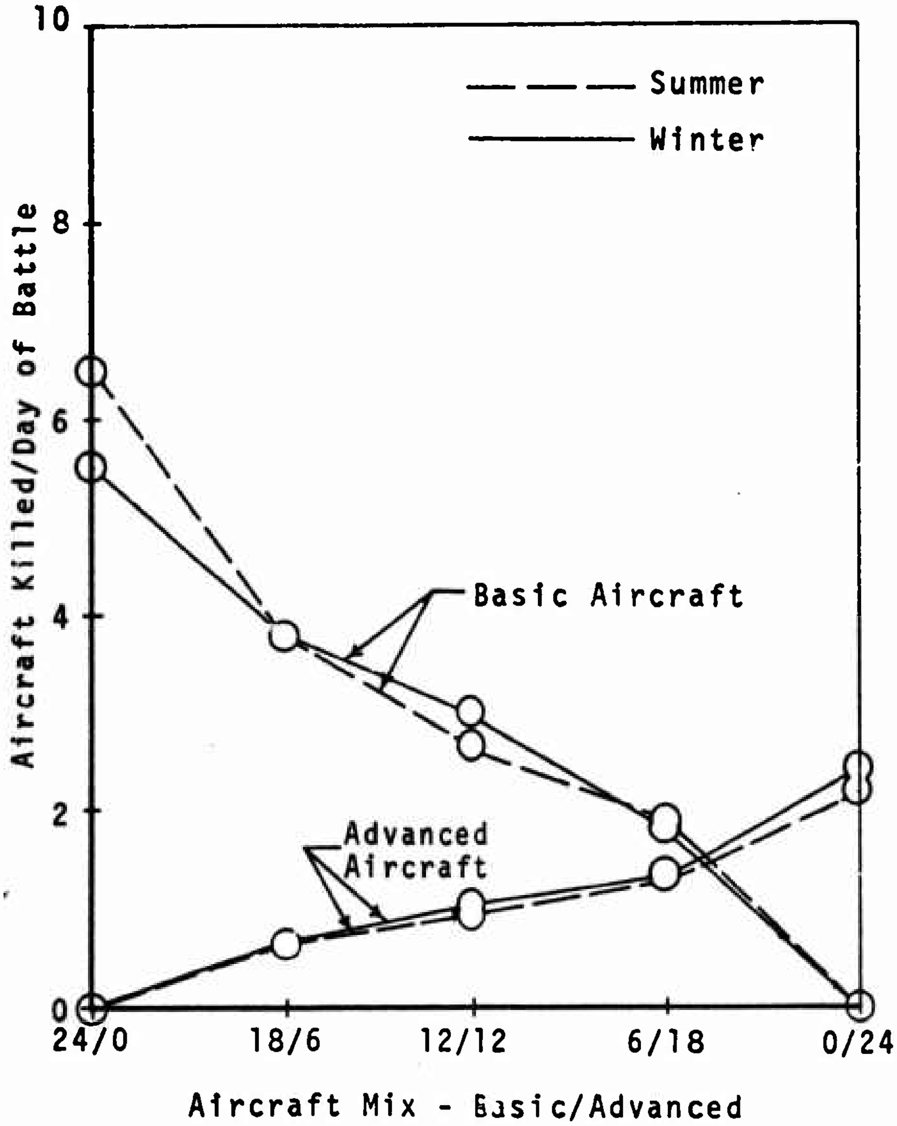


Figure 22 Aircraft Loss Rate for Various Aircraft Mixes

System Costs

In order to show the economic impact of the various aircraft mixes, costs were derived for each of the aircraft types. These costs, while representative of the types of systems considered in this study, are not to be associated with any actual existing or proposed equipment. Table 2 provides a breakdown and summary of costs for each type of aircraft.

The operating costs presented in Table 2 are peacetime operating costs and not wartime operating costs. Since maintenance and repair

demands upon the forward airbase would undoubtedly be higher during actual combat, one should also be concerned with maintenance resources

Basic Close Air Support Aircraft	Per unit cost
RDT&E	$ 0.3665 Million
Investment - Flyaway	1.6206
- Support	0.3723
10-year Operation & Maintenance	2.2286
Total 10-year Life Cycle Cost	$ 4.5880 Million
Advanced Avionic Equipment Add-On	
Incremental RDT&E	$ 0.0226 Million
Investment - Equipment	0.2100
- Support	0.0630
- Installation	0.0525
10-year Logistic & Maintenance	0.1512
Total 10-year Life Cycle Cost	$ 0.4993 Million
Summary - 10-year Life Cycle Cost Per Unit	
Basic Close Air Support Aircraft	$ 4.5880 Million
Advanced Close Air Support Aircraft	$ 5.0873 Million

Table 2 System Cost Summary

required during this time period. Study time did not permit the authors to analyze the maintenance problem in any great detail. One set of statistics which is related to maintenance requirements was recorded, however, for each of the five aircraft mixes tested in winter weather conditions (period of highest attrition due to enemy defenses). Table 3 shows, for each of the aircraft mixes, the expected number of

daily maintenance actions generated as a result of avionic equipment failures and battle damage.

Aircraft Mix - Basic/Advanced	24/0	18/6	12/12	6/18	0/24
Avionic Failures (Basic)/day	3.89	2.53	2.06	1.49	0.00
Avionic Failures (Advanced)/day	0.00	2.79	4.36	4.79	6.52
Battle Damage (Basic)/day	7.31	5.17	4.09	2.82	0.00
Battle Damage (Advanced)/day	0.00	0.84	1.63	2.18	3.91
Total Actions (All aircraft)/day	11.20	11.33	12.14	11.28	10.43

Table 3 Daily Maintenance Actions Per Squadron (Winter)

These actions do not represent all of the possible maintenance actions which could arise, but they do serve to highlight differences among the various aircraft mixes. Data in Table 3 shows that while there is a shift from battle damage repair to avionic equipment repair as the mix changes from all basic aircraft to all advanced aircraft, the total number of daily maintenance actions remains reasonably constant. Multiplying the number of expected maintenance actions by their respective expected completion times, we arrive at the expected total downtime rate of the squadron due to these two types of maintenance actions. Figure 23 shows this data for the five aircraft mixes. The bottom area in this graph represents maintenance due to battle damage while the shaded area represents the increment added for maintenance due to avionic equipment failures. The downtime rate (which is related to maintenance resource requirements) is also seen to have a relatively constant total value throughout the range of aircraft mixes.

The trends suggested in Figure 23 correspond to intuition in that the basic aircraft is expected to be more vulnerable to battle damage

while the advanced aircraft is expected to have a higher failure rate associated with its advanced avionic equipment. In addition, this data contradicts the notion that an advanced close air support aircraft places

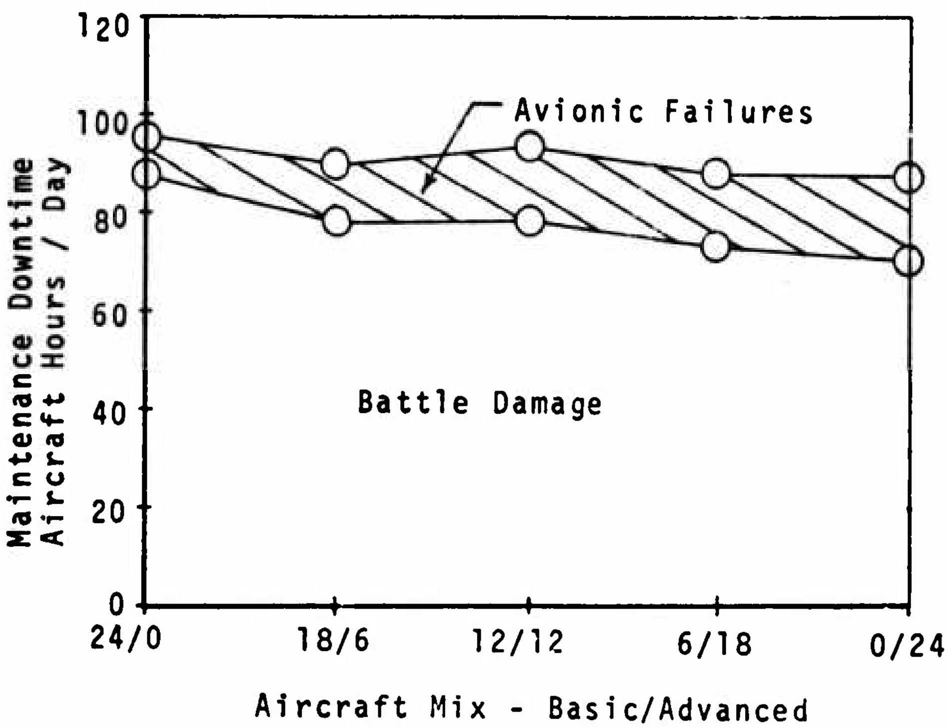


Figure 23 Maintenance Downtime for Various Aircraft Mixes

a heavier burden on maintenance facilities at the forward airbase. What, in fact, has happened is that the increased avionic equipment failure rate of this aircraft has been offset by its lower battle damage rate.

Because wartime maintenance requirements are an important aspect of the close air support problem, we recommend that this area receive further attention in future studies. Future users of the simulation model may wish to employ a more comprehensive set of maintenance events in the simulation program so that the above problem can be studied in depth. The present structure of the simulation program should allow this expansion to be accomplished in a relatively straight forward manner.

Cost Per Target Kill

Using the cost data presented in the last section, we are now able to compute the cost of resources consumed for every target destroyed. Figure 24 presents the expected cost per target killed for each of the five aircraft mixes and two general weather seasons.

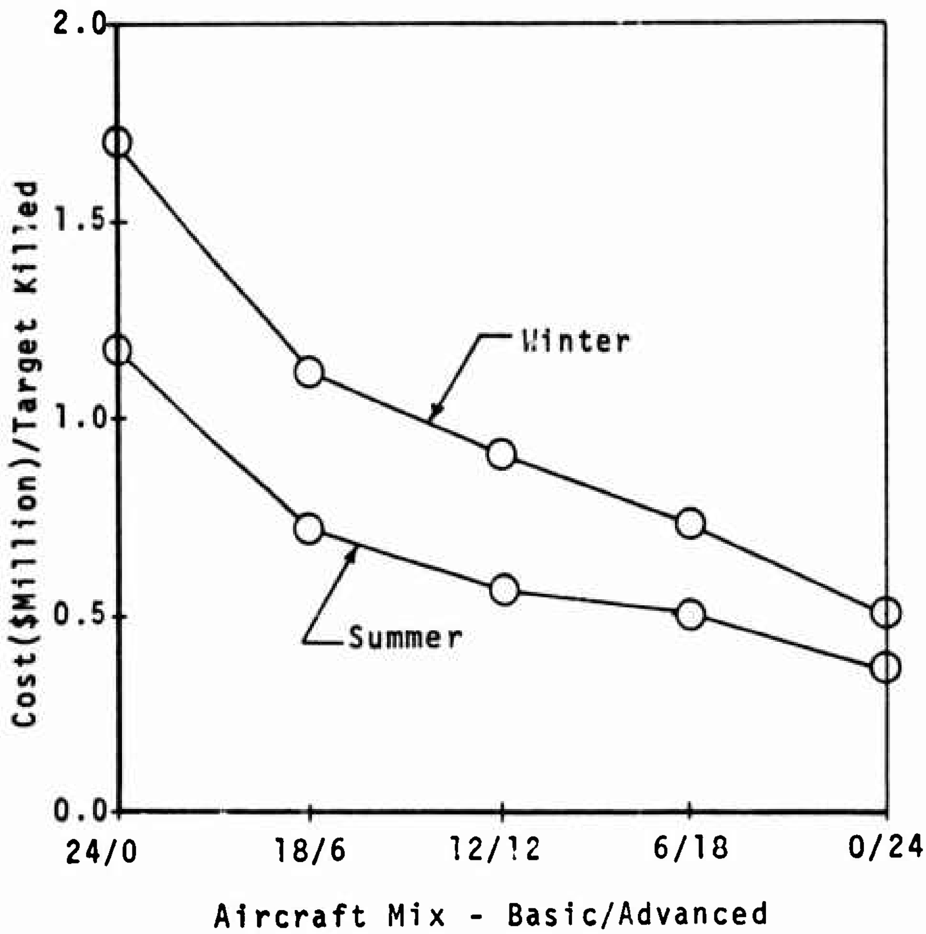


Figure 24 Ten-Year System Costs Per Target Killed for Various Aircraft Mixes

The cost figure used in each case is the 10-year life cycle cost per unit aircraft times the average number of aircraft attrited per target kill. The lower cost per target kill for the advanced aircraft largely reflects its improved survivability against target defenses. One other trend noticed in Figure 24 is the higher cost of providing close air support during winter weather conditions. Finally, the data

shows that the higher cost per aircraft associated with the addition of advanced avionic equipment is more than justified on an equal-effectiveness basis.

One additional cost not included in the above data is the cost of expended ordnance. The use of standoff weapons with the advanced aircraft makes this system more expensive to operate as compared to the basic aircraft using conventional ordnance. Although the actual expenditure of ordnance was not accounted for in the present version of the simulation model, future users may wish to do so. Appendix C does, however, present an approximate method for estimating such costs. Costs estimated in this Appendix correspond to the following three cases:

(1) Use of only basic aircraft against available targets.

(2) Use of the first preference aircraft against available targets.

(3) Use of only advanced aircraft against available targets.

Next, in approximate fashion, these costs were added to the 10-year life cycle costs of attrited aircraft. While some analysts may liken the addition of these two types of costs to a comparison of apples and

	Aircraft Mix - Basic/Advanced		
Summer	24/0	12/12	0/24
Attrition Cost/Target Kill	$ 1.183 M	$ 0.566 M	$ 0.366 M
Ordnance Cost/Target Kill	0.022 M	0.027 M	0.031 M
Total Cost/Target Kill	$ 1.205 M	$ 0.593 M	$ 0.397 M
Winter			
Attrition Cost/Target Kill	$ 1.704 M	$ 0.903 M	$ 0.632 M
Ordnance Cost/Target Kill	0.032 M	0.030 M	0.050 M
Total Cost/Target Kill	$ 1.736 M	$ 0.933 M	$ 0.632 M

Table 4 Total System Cost Per Target Killed for Various Aircraft Mixes

oranges, both costs do represent resources which must be expended in one way or another prior to or during the combat operation of the squadron. Hence, both costs are useful for comparing alternative aircraft mixes. Table 4 presents a summary of attrition, ordnance, and total costs per target killed for three of the aircraft mixes.

As shown by the data in Table 4, the addition of ordnance costs has not significantly altered the ranking of alternative aircraft mixes in our hypothetical example.

Optimization Criteria

While it is the intent of this study to provide some basis for selecting an optimum mix of aircraft in a close air support squadron, the authors do not wish to leave the impression that the entire problem can be reduced to mathematics or quantitative analysis. According to E. S. Quade:

> ... the systems analysis of military problems has many limitations - some inherent in all analyses, some, if not peculiar to military studies, at least more likely to be found there. As a consequence, it is seldom possible to prove to a decisionmaker by analysis that he should choose a particular course of action. (Ref 48:360)

Quade also goes on to mention four limitations that are particularly appropriate to our study of the close air support operation. (Ref 48: 361-363)

(1) Any analysis is necessarily incomplete since the analyst is limited in time and is unable to completely consider all aspects of the problem.

(2) Measures of effectiveness are inevitably approximate.

(3) No satisfactory way exists for predicting the future in terms of the possible situations and limitations facing the system.

(4) Systems analysis falls short of scientific research in that we cannot turn it into an exact science. Human judgment is not only relevant, but also indispensible.

Consequently, the authors chose to let the results of their analysis guide the selection of an optimum aircraft mix rather than allowing the results to automatically make this decision for them. To achieve this, one must not only recognize what is significant about these results, but also identify the areas of uncertainty.

In the hypothetical example, three trends support the selection of a squadron of all advanced aircraft as being optimum.

(1) The total cost per target killed is lowest for this alternative.

(2) The use of standoff weapons results in a low attrition rate (and low pilot loss rate) for this alternative.

(3) With this type of squadron, maintenance requirements at the forward airbase are not significantly higher than those generated by a squadron of all basic aircraft.

On the other hand, one trend is present which supports the use of a mix of 12 basic aircraft and 12 advanced aircraft in the squadron. This particular mix displays the highest target kill potential for the given target list used in this study. With a 12/12 mix of aircraft, the squadron has fewer target/weather scheduling restrictions and is better able to provide the right aircraft for each sortie request.

As for the areas of uncertainty, future targets may vary considerably from the six target types used in this study. As a result, the squadron may be unable to employ standoff weapons because of the proximity of friendly troops or other restrictions. Enemy defense suppression

techniques may increase the overall survivability of both types of aircraft thus reducing the attrition advantage of the advanced aircraft over the basic aircraft. Mission priorities may result in the squadron flying interdiction sorties where the advantage of standoff weapons might even be greater. Finally, cost estimates for both aircraft contain uncertainties which affect the ranking of attractive alternatives.

To explore in detail any one of the above areas for the present study would not result in very useful guidelines: such detail varies with each individual study and range of alternatives. It should suffice to say here that every area mentioned above is important and must be weighed by the decisionmaker along with the quantitative data already presented.

For the hypothetical example, it is not important that the authors select a final "optimum" mix of aircraft since it is not the intent of this study to "sell" any particular concept of operation or future system. What the authors hope has been shown through the use of this example problem is the possible significance of selected variables on the operation of a close air support squadron and how this information might influence the selection of aircraft. To carry this intent one step further, the last section of this chapter presents a brief look at two sensitivity studies which were carried out during the time remaining for this research effort.

Sensitivity Analyses

The first departure made from the preceding baseline case involved scheduling restrictions imposed on the advanced aircraft. In a previous section it was found that the number of targets killed per day by the squadron reaches a peak value at a mix of 12 basic aircraft and 12

advanced aircraft. As more advanced aircraft are added to the squadron, the number of targets killed per day begins to drop off. To see just how the scheduling restrictions of the advanced aircraft influenced this trend, a series of fifteen simulation runs were made using winter weather data and revised aircraft preference codes. In place of those codes presented in chapter IV which denied target types 3, 4, 5, and 6 to the advanced aircraft in weather state 4, new codes were input into the model which removed such restrictions. As a result of making these targets available to the advanced aircraft in weather state 4, the number of targets killed per day rose only slightly for those squadrons containing a large number of advanced aircraft. On the other hand, the cost per target killed increased rather significantly for these same squadrons. Figure 25 shows the original cost per target killed along

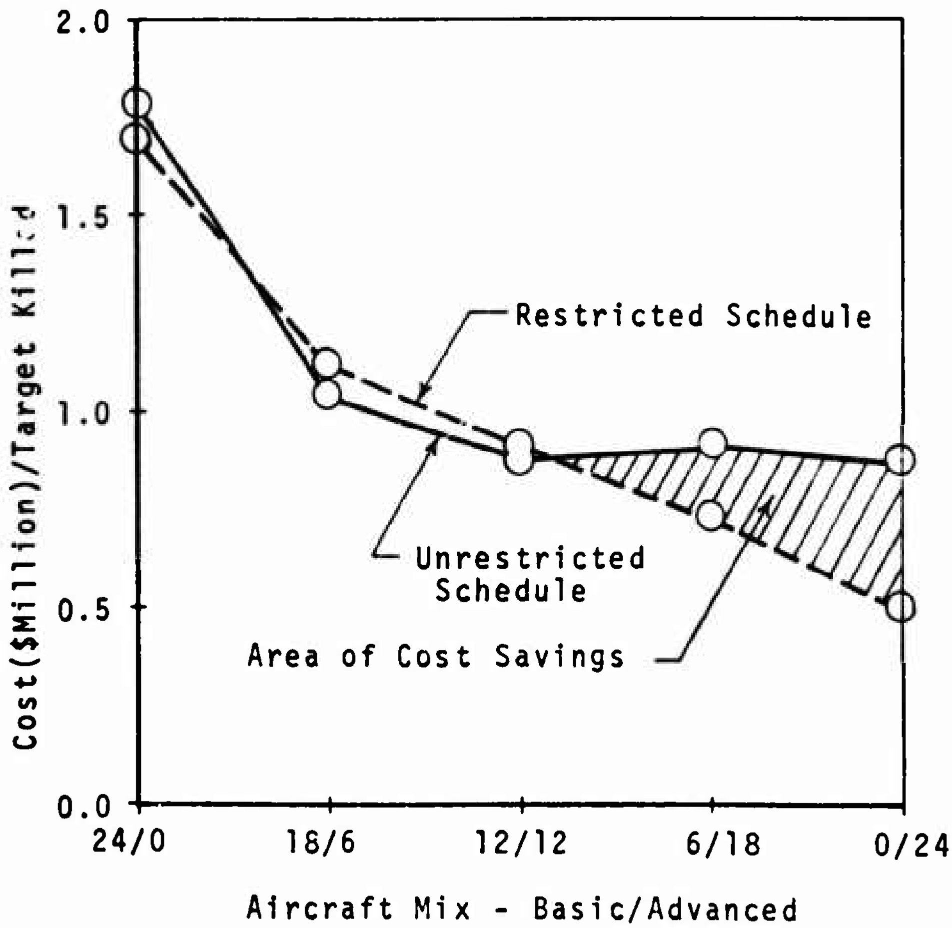


Figure 25 Ten-Year System Costs Per Target Killed for Both Restricted and Unrestricted Target Scheduling

with the revised cost per target killed with no restrictions placed on the scheduling of the advanced aircraft. This data indicates a significant savings in cost per target killed with the use of restricted scheduling of aircraft.

A second sensitivity analysis was performed in the areas of aircraft survivability and weapon effectiveness. Specifically, the authors explored the following cases to see where there existed potential areas of cost saving in the operation of the squadron.

(1) Eliminate aircraft attrition due to area defenses.

(2) Eliminate aircraft attrition due to target defenses.

(3) Give the aircraft a perfect weapon to carry.

Obviously, it would be nearly impossible to achieve any one of these goals, however, these cases serve as a limiting situation in each of the above areas. To test the effect of such changes on the operation of the squadron, a series of eighteen additional simulation runs were made using a squadron of 24 advanced aircraft in both summer and winter weather conditions. Figure 26 presents the expected number of targets killed per day by the squadron for each of the above cases plus the original baseline case. Results are averaged from 270 days of simulated battle. As shown by the data, there are only modest increases in the number of targets killed per day with the largest increase associated with the elimination of target defenses.

Figure 27 presents corresponding aircraft attrition data for each of the three special cases plus the original baseline case. In this figure, the effect of eliminating target defenses is more noticeable. It follows that this substantial reduction in aircraft attrition produces a lower cost per target killed for the case with no target defenses. Table 5 presents these costs for all cases.

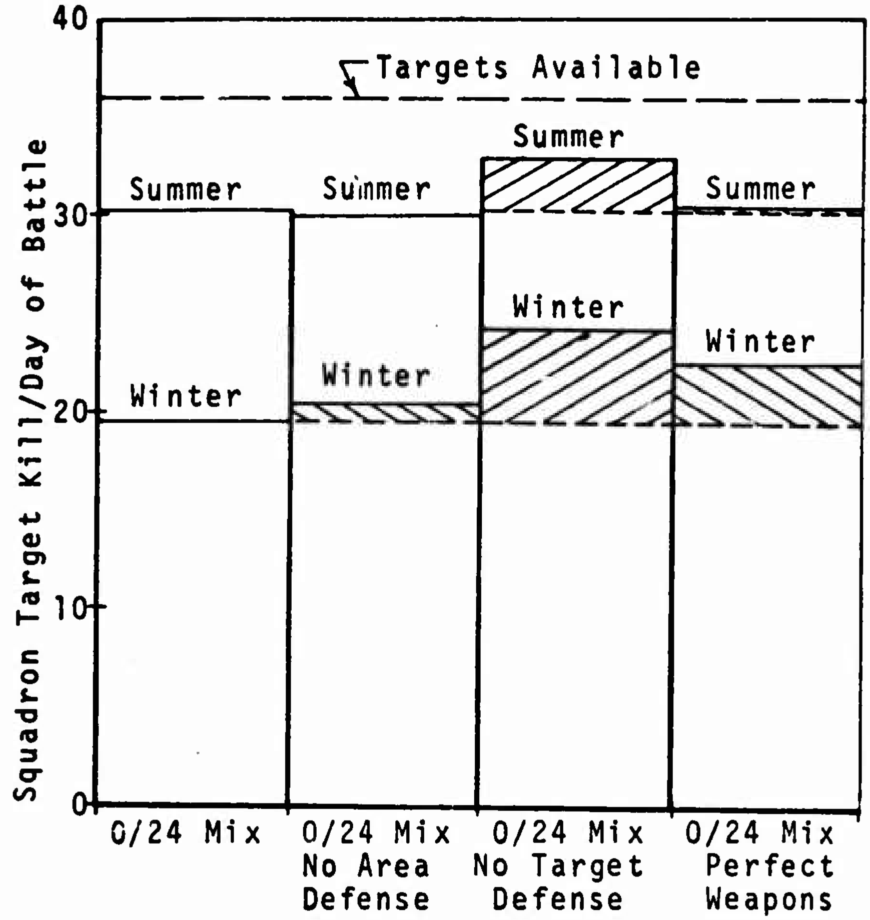


Figure 26 Squadron Target Kill for Various Defense Levels and for Perfect Weapons

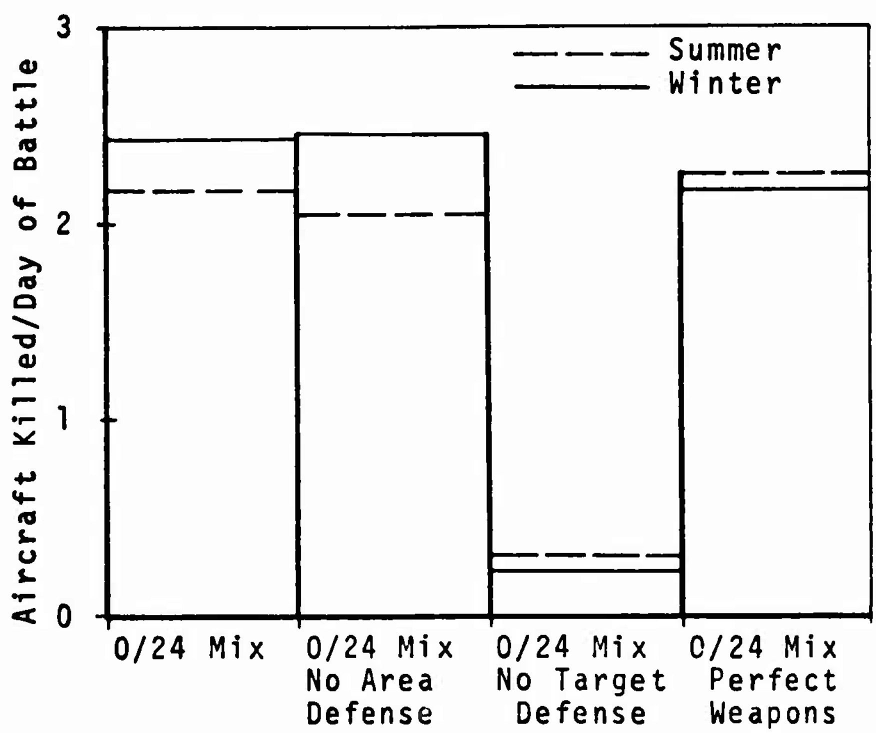


Figure 27 Aircraft Loss Rate for Various Defense Levels and for Perfect Weapons

	Cost Per Target Killed	
	Summer	Winter
Baseline Case	$ 0.366 M	$ 0.632 M
No Area Defenses	$ 0.348 M	$ 0.617 M
No Target Defenses	$ 0.046 M	$ 0.047 M
Perfect Weapons	$ 0.376 M	$ 0.489 M

Table 5 Ten-Year System Cost Per Target Killed for Various Defense Levels and for Perfect Weapons

At this point in time, the cost savings potential suggested in Table 5 are purely speculative and associated only with the hypothetical example. It is recommended, however, that future studies uncover these types of trends so that such potential savings can be exploited through the development of improved equipment and refined tactics. The simulation model presented in this paper would be one available tool for evaluating new and improved equipment and operating tactics.

Conclusions

In this chapter, the authors have shown through the use of an example problem that both weather conditions and variations in avionic equipment have a significant amount of influence on the operation of a close air support squadron. By presenting selected statistics from an analysis of this example problem, the authors have demonstrated that the simulation model can (1) provide useful information to the decisionmaker for optimizing the mix of aircraft within a squadron, and (2) serve as a useful tool for performing sensitivity analyses on portions of the close air support operation. It is hoped that many of these suggestions will be of use in future studies of this general problem and that this paper has been able to highlight many of the significant variables

which control the squadron's operation. Finally, the authors hope that they have left some encouragement to those wishing to pursue the analysis of the close air support mission through the use of simulation.

VII. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective of developing a computer simulation model of a close air support engagement has been realized in this research effort. The model was designed specifically to highlight differences in effectiveness, vulnerability, availability, and cost between aircraft with two different degrees of avionics sophistication. It has proved itself to be suitable for such a study, and much insight into the avionics force-mix question was gained through the model's development and preliminary use.

Analysis of the model itself yielded the results summarized below:

(1) The approximation of a continuum of occurrences by discrete events through the SIMSCRIPT programming language did not result in serious error.

(2) One long simulation run or several shorter runs provided equally satisfactory results.

(3) The effect of initial conditions on steady-state results was insignificant for the length of simulation periods used in the study.

(4) Effects of autocorrelation on the model results were considerably reduced after three simulated days of CAS operations. However, the presence of autocorrelation was used to gain insight into the operation of the model.

(5) For equal sample sizes general weather conditions significantly influenced the amount of confidence in steady-state results.

It was concluded that the model does not contain any strong, built-in biases that would tend to produce inaccurate results. Additionally, the importance of clearly defining the objectives in a simulation was

brought out in the development of this model. It was concluded that in planning a series of computer runs, merely to accept the recommendations of certain writers in the field of simulation without first investigating the effects on the individual study could lead to wasteful and misleading results.

A hypothetical example was used to demonstrate the utility of the simulation. No attempt was made to draw conclusions about any real-world aircraft or situation from the results of this example; however, these results supported the validity of the simulation in that they generally approximated conditions that one might expect in an actual CAS engagement. The results are summarized below:

(1) The "all Type 2" squadron had a higher sorties-flown-per-sortie-requested ratio than the "all Type 1" squadron.

(2) In winter weather, a 12/12 mix was optimum in terms of sorties flown/sortie requested.

(3) There was a decrease in the number of targets killed per day from summer to winter weather conditions confirming the assertion that even "all-weather" aircraft operate at reduced effectiveness in poor weather conditions.

(4) The number of targets killed per day was maximized using the 12/12 mix.

(5) The increased survivability and increased single-pass-target-kill probability of the advanced aircraft did not produce a striking increase in the number of targets killed per day.

(6) General weather conditions normally persisted no longer than three days.

(7) Fewer aircraft were lost per day as more advanced aircraft were added to the squadron.

(8) Aircraft loss rates were approximately the same for summer and winter weather conditions.

(9) Increased maintenance downtime due to avionics failures in Type 2 aircraft was offset by lower downtime due to battle damage of Type 2 aircraft.

(10) Close air support cost more in the bad weather conditions.

(11) The higher cost per aircraft associated with the addition of advanced avionic equipment was more than offset by greater effectiveness measured by cost/target killed.

(12) Ordnance costs did not seem to significantly affect the results.

(13) The restricted scheduling policy as originally programmed did indeed result in increased savings in cost/target killed.

Conclusions

The analysis of the model and consideration of the results from the hypothetical example led to the following specific conclusions:

(1) Weather conditions and variations in avionic equipment have a significant impact on the close air support operation.

(2) The model presented in this paper can provide useful information to the decision-maker for optimizing the mix of aircraft within a squadron.

(3) Simulation appears to be a viable technique for studying this type of force-mix problem.

(4) The model can serve as a useful tool for performing sensitivity analyses on portions of the CAS operation, and the sensitivity approach is extremely valuable for isolating sources of savings.

(5) Certain weather persistence data can be approximated by a geometric probability density function, and a Markov model provided a good representation of the weather throughout the simulation experiments.

Recommendations for Further Study

Since this thesis was an initial attempt at modeling through simulation the particular force-mix problem considered, by necessity many aspects of the problem were left unexplored. The exclusion of these other factors does not imply that they are any less important than those considered, but only that in the interest of academic expediency, there was not time to include them. For this reason, the authors recommend that further work on the model or with the model be done along the following lines:

(1) Any of the variables held constant throughout the analysis (see Chapter VI) could well be the subject of further study through the sensitivity approach.

(2) The inclusion of a more comprehensive set of maintenance and support events would add greater realism and validity to the simulation. Included in this could be a more detailed consideration of the problem of replacing lost or severely damaged aircraft.

(3) Some means of accounting for ordnance expended and lost should be included in the simulation.

(4) The model could be expanded to allow the aircraft to make more than two passes on a target. Also, providing for the multiple-aircraft mission and permitting more than one target per sortie to be struck would add greater dimension to the model.

(5) The scope of the simulation could be increased to cover the operation of a wing or even theater sized force.

(6) It would be very informative if further sensitivity analyses were performed in the areas of restricted scheduling, aircraft survivability, and weapons effectiveness in the manner illustrated in Chapter VI.

(7) Adding the interdiction mission to the scenario would greatly expand the applicability of the model, but would require extensive revision of the simulation.

(8) Spectral analysis could be employed to investigate the auto-correlation of the variables in the simulation.

(9) The number of points in the simulation at which aircraft are tested for avionics failures could well be increased -- at least to include the case of a ground abort of the sortie due to avionics failure.

(10) The effort devoted to modeling the weather was quite cursory and primarily aimed at fulfilling the need of the simulation for an adequate representation of weather effects. Much more detailed work in this area could prove to be quite valuable. Specifically, further investigation of the probability distribution of weather persistence is warranted. Also, the study of weather as a semi-Markov process could prove fruitful.

It is hoped that this paper will prove to be a stimulus for further analytical effort directed toward the avionics force-mix question, and that the simulation approach will be considered as a strong method for conducting further studies. The successes and failures of this paper should make future endeavors of this type a little less difficult to

perform. If the work done on this thesis is used in just one real application that is of value to the Air Force, then all the time and effort expended on it will be worthwhile.

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APPENDIX A

SIMULATION MODEL

Appendix A

Simulation Model

This appendix presents a detailed description of the SIMSCRIPT simulation model used to study the operation of the close air support squadron. In addition, this narrative should serve as a user's manual for those wishing to utilize this simulation program in future studies.

As presented in Chapter II, the general scenario assumed in the construction of the computer program consisted of a single squadron of close air support type aircraft operating out of a forward airbase. Within the squadron there can exist up to two different types of close air support aircraft. For the present study, the differences between these two types of aircraft were confined to variations in avionic capabilities and associated ordnance loads. However, the model is also capable of accounting for more extensive differences so long as these differences can be expressed in terms of the model inputs.

The simulation begins with the random generation of sortie requests from a list of targets specified by the model user. As sortie requests are generated, they are filed in a queue which ranks them according to the expiration time of their target. Those targets which have more immediate expiration times are considered first. When aircraft become available sortie requests are filled according to their first and second choice of aircraft type. The use of this preference system in assigning aircraft to targets allows the user some control over the scheduling the close air support operation.

In the present model single aircraft flights are scheduled against single targets. The addition of multiple aircraft, multiple target sorties was considered during the development of the simulation model

but later rejected by the authors since it was felt that this feature would not significantly enhance the present study. The single aircraft, single target sortie was considered adequate for demonstrating the effectiveness of various aircraft mixes operating under variable weather conditions.

Once an aircraft is assigned to a particular sortie, the aircraft proceeds to penetrate the area defenses across the forward edge of the battle area (FEBA). If the aircraft survives area defenses, it continues on to the target area where several event outcomes are tested. First, a check is made to see whether a forward air controller (FAC) is available at the target site. If a FAC is available (or the sortie can be flown without a FAC), the reliability of the aircraft's avionic equipment is tested. This test is made only once during each sortie and determines if the sortie must be aborted due to an avionic equipment failure. Since it is highly unlikely that an aircraft's avionic equipment would actually fail only at this given point, the logic employed in the simulation model represents a simplification of the real world. It should be noted, however, that this simplification was made in the model because of limited time during the study. Future users of this simulation program may wish to reconsider the method of accounting for avionic equipment failures if they feel that this has a significant amount of influence on the model output.

If the avionic equipment has failed, the sortie is aborted and the aircraft is directed to egress back through area defenses to the forward airbase. If the avionic equipment is found to be operating, the aircraft makes its initial pass at the target. A given pass against the target consists of (1) testing the survivability of the aircraft against target defenses, and (2) testing the success of the weapon against the target. A maximum of two passes per target is allowed in the present

simulation model. If the target has not been destroyed after the second pass, the original sortie request is replaced in the scheduling queue so that it might be reconsidered. Another aircraft may be assigned to this target if the lifetime of the target has not been exceeded.

At various points in the model the survivability of the aircraft is tested as explained above. Each of these tests include (1) a check to see if the aircraft receives a hit from enemy defenses, and (2) a check if the aircraft is hit to determine whether the aircraft is killed or just damaged. Damaged aircraft are directed to return to the forward airbase for repair while destroyed aircraft are replaced. The present model assumes that destroyed aircraft are replaced exactly twelve hours after the loss. This assumption represents a desire during the present study to keep the number of available aircraft reasonably constant for the squadron. Future users of this model may wish to modify this assumption to allow for either later replacement or no replacement of lost aircraft.

Several maintenance cycles exist within the simulation to account for the time expended repairing battle damaged aircraft, repairing avionic equipment failures, refueling, and reloading ordnance. While these maintenance cycles do not account for the complete spectrum of maintenance actions encountered by a close air support squadron, they do serve to highlight the differences in reliability and maintainability for the two types of aircraft considered in the present study. Again, future users of this model may wish to add other maintenance cycles if they consider them appropriate. An additional assumption for these maintenance cycles is that there exists no shortage of either personnel or facilities. Since it was not the purpose of this study to do an in-depth investigation of maintenance facility requirements or personnel requirements at the

forward airbase, this assumption was considered to be reasonable. Repair times were generated from a logarithmic normal distribution. This formulation was selected because available data used during the study was based on this type of distribution. Once an aircraft completes the appropriate maintenance actions, it is returned to the line.

As shown in Figure 28, the network of events in the SIMSCRIPT simulation program closely resembles the scenario described in Chapter II. Arrows connecting the various event subprograms depict the possible sequences of occurrence during a typical model exercise. Before outlining each of the event subprograms, we present a few comments on why SIMSCRIPT programming language was selected for use in this study. A basic understanding of the programming language will allow the reader to gain a better concept of the model's operation.

Candidate programming languages investigated for this simulation included FORTRAN, GPSS, SIMPL, and SIMSCRIPT. While FORTRAN is a general purpose scientific language familiar to most analysts, the others represent languages specifically tailored to simulation programs. Emshoff and Sisson give a comparison of these and other languages in Reference 13. Early in the study it was concluded that SIMSCRIPT represented the most flexible approach to constructing the program. Primary reasons for its selection were (1) orientation of the language towards event-to-event simulations, (2) the automatic time accounting feature of the language, and (3) the availability of FORTRAN and FORTRAN EXTENDED library functions within the language. Several excellent introductions to SIMSCRIPT programming may be found in References 9 and 43.

As stated above, SIMSCRIPT is a language oriented towards event-to-event simulations. This implies that the analyst must conceive of the operation to be simulated as a network of discrete events rather than a

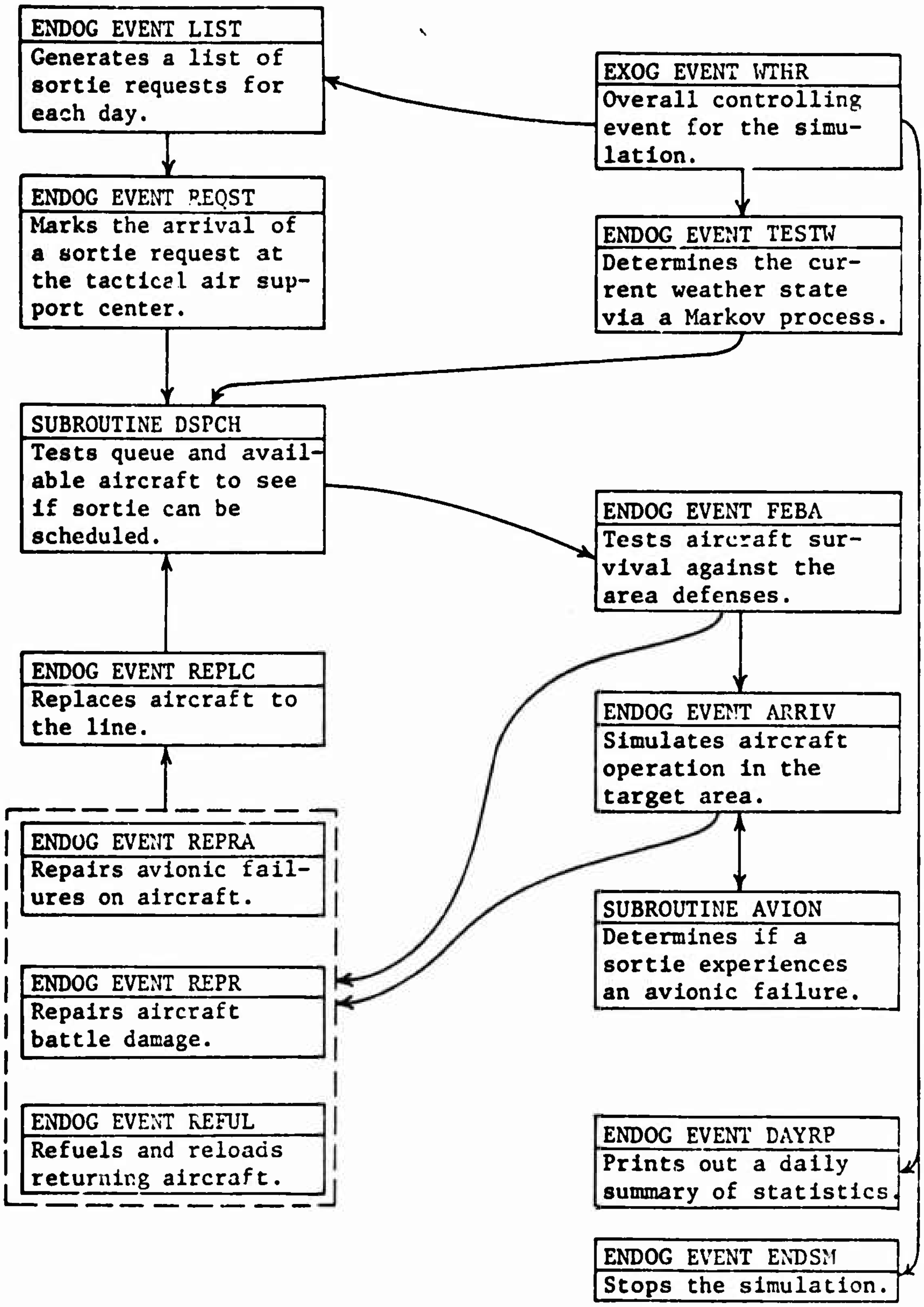

Figure 28 SIMSCRIPT Simulation Model

continuum of occurrences. Each of the events is connected to others by a logic system specifying the order in which they occur in time. One limitation inherent in this approach is that phenomena which occur continuously over time must be approximated by a series of discrete events. The significance of this limitation depends upon the nature of each simulation. For the close air support study, the authors concluded that the representation of this operation by a network of discrete events did not result in serious error.

An additional feature of SIMSCRIPT pertinent to this discussion is the concept of a temporary entity. Within the simulation these entities may be created and used to represent specific items flowing through a network of transactions in the model. In the close air support model the temporary entity concept was used to represent a sortie request. The request was created at one point in the simulation, was stored in a queue until the appropriate aircraft became available, was carried along with the aircraft as the sortie was flown, and was destroyed after the associated target was killed. Because temporary entities are actually memory addresses inside the computer, each entity can be assigned a list of attributes. Typical attributes for a sortie request included target type, target lifetime, and preference of aircraft type. As can be seen, the concept of a temporary entity provides a unique method for structuring portions of the simulation.

With reference to Figure 28, the authors now present a brief description of the algorithms contained in each event subprogram.

Exogenous Event WTHR

This event is the overall controlling event for the simulation.

Its primary purpose is to schedule the occurrence of the following events:

(1) LIST is scheduled at the beginning of each simulated day to generate a list of sortie requests.

(2) TESTW is scheduled every hour to account for changes in the weather state.

(3) DAYRP is scheduled at the end of each day to print out a summary report of what happened during that day.

The scheduling of TESTW depends upon the time interval used for the Markovian weather model. The increment of time chosen for this study was one hour based on available weather data. If a different time increment were used in future studies, the scheduling of TESTW would have to be modified.

The event WTHR is labeled as an exogenous event since its occurrence is scheduled via external input to the simulation model. All of the other events are scheduled internally by one another and, hence, they are called endogenous events.

Endogenous Event LIST

This event occurs at the beginning of each simulated day and creates a list of random sortie request events named REQST. The present version of this subprogram uses two independent random numbers to select the time of occurrence of the sortie and the associated type of target. After the entire list of sortie requests are generated, LIST prints out a summary total of sortie requests assigned to each of the six types of targets available in the model. Model inputs allow the user to specify the number of sortie requests created during each of the four six-hour periods in a day.

Endogenous Event REQST

This event marks the receipt of a sortie request by the tactical air support center. Each sortie request is first assigned a target lifetime associated with the particular type of target for that sortie. Next, two preference codes are assigned by target type which will later determine the type of aircraft allocated to that sortie. These codes are ten-digit integers of the following form:

WXCD1 =	2	2	2	2	2	2	1	1	1	0	← first choice of aircraft
	10	9	8	7	6	5	4	3	2	1	← weather state
WXCD2 =	0	1	1	0	1	1	0	2	2	0	← second choise of aircraft
	10	9	8	7	6	5	4	3	2	1	← weather state

2 = aircraft type 2

1 = aircraft type 1

0 = neither aircraft can be assigned

The new sortie requests are next filed in a ranked queue named TASC which orders them by their time of expiration. This expiration time is computed by adding the target lifetime to the present clock time. Sortie requests, once filed in TASC, remain in this queue until they are removed by subroutine DSPCH.

Subroutine DSPCH

This subroutine examines the list of sortie requests filed in the queue called TASC and schedules sorties to be flown by available aircraft. The logic employs two weather codes, WXCD1 and WXCD2, assigned to each sortie request and first tries to allocate an aircraft on the basis of WXCD1. If the first aircraft preference is not available, the subroutine then attempts to allocate an aircraft on the basis of WXCD2. If WXCD2 specifies that neither aircraft type can be assigned, the subroutine temporarily sets aside this sortie request and begins the entire

procedure again with the next sortie request filed in TASC. This general process continues until all possible aircraft/sortie request matches can be made. Sortie requests not filled are refiled in TASC for later consideration. Sortie requests which have exceeded their expiration time are dropped from the queue and destroyed.

Subroutine DSPCH is called from several different locations in the simulation model. These locations represent the various times when sorties might be initiated. They include the following event times:

(1) An aircraft is returned to the line.

(2) A previously scheduled sortie is aborted and the sortie request is refiled in TASC.

(3) A new sortie request is received at the tactical air support center.

(4) The weather changes from a state in which aircraft are grounded to one in which aircraft can be flown.

One simplifying assumption was made with regard to the weather state encountered by each sortie. The weather is assumed to remain constant throughout a given sortie even though the sortie may extend beyond the period of time the actual weather is constant. This simplification avoids the problem of having to abort a sortie midway through its completion because of bad weather. The weather state used for any given sortie is equal to the actual weather state of the simulation when the sortie was initiated. It was felt that this simplification would have only a minor effect on the final results of the simulation model.

Endogenous Event FEBA

As implied by its name, this event represents the aircraft's penetration of area defenses located between the forward edge of the

battle area and the target area. A test is made to first determine whether or not the penetrating aircraft is hit by these defenses. A random number from a uniform (0-1) distribution is compared against a probability of hit estimate. If the aircraft has not been hit, the subprogram schedules event ARRIV to occur at the present time plus a value called TARG. If the aircraft is hit by the defenses, a second test is made to determine whether the aircraft is damaged or destroyed. This second test is similar in nature to the first test and uses an independent random number. If the aircraft is destroyed, event REPLC is scheduled to occur at the present time plus one-half day. If the aircraft is damaged, event REPR is scheduled to occur at the present time plus a value called RET.

Endogenous Event ARRIV

This event is the largest subprogram of the model and represents the close air support aircraft operating in the target area. The subprogram begins by determining whether or not a forward air controller is available for directing the aircraft to its target. Again, this is a probabilistic test using a uniform (0-1) random number. If a forward air controller is not available, the routine then checks to determine whether the sortie can be flown without assistance. The program user may specify this information by type of aircraft and type of target. If the target cannot be attacked, the sortie is aborted and the sortie request is refiled in TASC. The egressing aircraft is checked for (1) an avionic equipment failure, and (2) survival against area defenses. The survivability tests are similar to those described for the event FEBA, and they can result in the scheduling of events REPLC or REPR if the aircraft is hit by defenses. The returning aircraft

which survive area defenses are then tested for an avionic equipment failure by calling subroutine AVION. Calling this subroutine determines whether or not the aircraft's avionic equipment have experienced a failure. If the avionic equipment is operating, event REFUL is scheduled to occur at the present time plus a value called RET. If the aircraft experiences an avionic equipment failure, event REPRA is scheduled at a similar time.

If a forward air controller is available or the sortie can be flown without one, the subprogram checks the status of the attacking aircraft's avionic equipment. Again subroutine AVION is called for this test. It should be noted that the structure of the program allows subroutine AVION to be called only once for any given sortie. If the aircraft experiences an avionic failure in the target area, the sortie is aborted and the sortie request is refiled in TASC. The egressing aircraft is then tested against area defenses in a manner described above. If the returning aircraft survives area defenses, event REPRA is scheduled. If the avionic equipment is found to be operational, the aircraft proceeds to attack its assigned target.

In the present program a maximum of two passes is allowed per target. On each pass the subprogram first tests the survivability of the attacking aircraft against target defenses. This test is similar to the one made against area defenses and the various outcomes result in the scheduling of appropriate events. If the aircraft survives target defenses, a final test is made to determine the success of the single pass against the target. If the target is not destroyed, a second pass is made. If the target is not destroyed after two passes, the sortie request is refiled in the queue named TASC.

Once an aircraft completes its attack of the assigned target, the subprogram tests the survivability of the egressing aircraft against area defenses. Again, the procedure of testing survivability against enemy defenses is similar to others mentioned before.

At this point, it would be well to make a few comments about the probability estimates used in this subprogram as well as in the subprogram called FEBA. Both the probability of survival against area defenses and the probability of survival against target defenses are assumed to reflect optimum penetration tactics. In addition, the probability of killing the assigned target is generally related to the probability of survival against target defenses. For the present study, these two numbers were generated for each target/aircraft type/weather state combination using the particular tactic and ordnance combination that resulted in the highest ratio of targets killed to aircraft lost. Future users of this model should be aware of these types of relationships so that the proper set of probability estimates are used.

With regards to the probability of a FAC being available at the target site, the authors recognized that a sortie would probably not be scheduled when it is known in advance that a FAC were not available. Otherwise, the improper scheduling of a sortie would unnecessarily subject an aircraft to area defenses. One may, on the other hand, interpret this probability as the probability of a FAC not being able to remain at the target site from the time a sortie is scheduled to the time the attacking aircraft arrives at the target site.

Subroutine AVION

Several points in the previous discussion refer to subroutine AVION which determines the operating status of the aircraft's avionic equipment.

This subroutine uses an exponential distribution failure law based on the number of sorties flown by each type of aircraft in the squadron. Although many analysts consider the failure of equipment to be related more properly to operating hours, References 12 and 3 suggest that it is more appropriate to base this failure phenomena on the number of sorties flown. Coincident with this idea is the fact that most available maintenance data is generated originally on the basis of sorties and later converted to a flying hour basis.

Time limitations of this study necessitated the use of an exponential distribution for the failure law. For future studies, it is suggested that a Wiebull distribution with its one additional parameter would give a more accurate representation of the failure phenomena in avionic equipment. The equation

$$NST1 = 0.5 + MTBF1 * \log_e(1.0 - R)$$

where NST1 = actual number of sorties flown by aircraft type 1 between avionic equipment failures

MTBF1 = mean number of sorties flown by aircraft type 1 between avionic equipment failures

R = a random number from a uniform (0-1) distribution

is used to generate the random number of sorties flown by aircraft type 1 before the next avionic equipment failure. A new value is computed each time a failure occurs. Proper accounting of the number of sorties flown by type 1 aircraft is achieved by calling subroutine AVION exactly once during each sortie. A value of 0.5 is added in the above equation to adjust for roundoff errors in truncating NST1 to integer form. A parallel relationship exists for type 2 aircraft.

Endogenous Event REPRA

This subprogram is one of three maintenance events included in the simulation. As aircraft return to the base with avionic equipment failures, this event accounts for the time spent in repairing and servicing the aircraft. Repair times are generated randomly from a logarithmic normal distribution. This distribution allows repair time data to be fit with both a shape and scale parameter. The logarithmic transformation prevents the occurrence of negative repair times. The procedure for generating a value from this distribution is presented below.

(1) The arithmetic mean repair time for each type of aircraft is stored in the variables called MTBA1 and MTBA2.

(2) The arithmetic standard deviation is assumed to be 29 percent of the arithmetic mean following the suggestion of Major D. Tetmeyer of the Air Force Human Resources Laboratory. (Ref 58) This percentage is assumed to represent the average for most equipment aboard the aircraft.

(3) Parameters for the transformed normal distribution are calculated from the following relations. (Ref 5:62)

$$\mu = \log_e \frac{\text{MTBA1}}{(1.0841)^{1/2}}$$

$$\sigma^2 = \log_e (1.0841)^{1/2}$$

(4) Although several computational techniques are available for generating standard normal deviates, the following method is used. (Ref 1:935)

$$n = (-2*\log_e U_1)^{1/2} * \cos(2\pi U_2)$$

where U_1 and U_2 are a pair of independent uniform (0-1) deviates.

(5) The final value for repair time is obtained by transforming back to the logarithmic normal distribution.

$$TR = \text{repair time} = e^{(\sigma n + \mu)}$$

Before scheduling the event REPLC, the subprogram adds a refueling and reloading time to the repair time, TR.

Endogenous Event REPR

This subprogram is identical to REPRA except that different mean repair times are used. Whereas the event REPRA considers aircraft returning with avionic equipment failures, the event REPR considers battle demaged aircraft returning to the forward airbase.

Since the present simulation makes a replacement of all destroyed aircraft within one-half day, the program user may desire the option of redefining what constitutes a lost aircraft. If extensive battle damage has been incurred by a particular aircraft, it would seem likely that this aircraft would not be available for quite some time. By defining this aircraft as essentially being lost, we would be replacing it sooner than would be possible through the use of REPR. If one desires to combine extensively damaged aircraft and destroyed aircraft into a single category, then appropriate adjustments would have to be made in (1) the mean time to repair values used in REPR, and (2) the probability of damage values used in ARRIV and FEBA.

Endogenous Event REFUL

This final maintenance event accounts for all aircraft returned to the base undamaged and without avionic equipment failure. The refueling and reloading times are fixed values for each type of aircraft. The event REFUL schedules REPLC to occur at the present time plus the value stored in either RFL1 or RFL2.

Endogenous Event REPLC

This event marks the return of an aircraft to the line by adjusting the number of available aircraft. This event is scheduled either 12 hours after the loss of any aircraft or after the completion of any one of the maintenance events.

Endogenous Event TESTW

This subprogram employs the Markovian model of weather presented in Chapter III. A single matrix is used which describes the transition probabilities from one weather state to another. Given the current weather state, this subprogram selects the appropriate row from the matrix shown below.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdot\ \cdot\ \cdot\ \cdot & a_{1\ 10} \\ a_{21} & a_{22} & \cdot\ \cdot\ \cdot\ \cdot & a_{2\ 10} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ a_{10\ 1} & a_{10\ 2} & \cdot\ \cdot\ \cdot\ \cdot & a_{10\ 10} \end{bmatrix}$$

Given that the appropriate row has been selected, the new weather state is found by computing a row sum for each weather state.

In the row

$$\begin{bmatrix} a_{21} & a_{22} & \cdot\ \cdot\ \cdot\ \cdot & a_{2\ 10} \end{bmatrix}$$

the i^{th} row sum as defined above would be given by $\sum_{n=1}^{i} a_{2n}$. The new weather state is then determined to be that state whose row sum first exceeds a random number drawn from a uniform (0-1) distribution.

Endogenous Event DAYRP

This event is scheduled by WTHR to occur at the end of each simulated day. The purpose of DAYRP is to produce a daily report of what has

happened in the simulation. A sample printout is shown in Figure 29. Another version of this daily report is shown in Figure 30. While the report format shown in Figure 30 does not contain quite as much information as the format in Figure 29, one can see that this latter format results in fewer number of output pages (a consideration to make when simulating a long period of time). One additional output format available to the user is shown in Figure 31. This output represents an event by event description of what happened during the simulation. Because of the excessive length of this type of printout, the event by event description is generally obtained only for checking out the operation of the program.

The model user may specify the type of program output with the input variable called IWRIT. The different values of IWRIT are given below.

IWRIT = 1 print out the daily summary shown in Figure 29

2 print out the event list shown in Figure 31

3 print out the daily summary shown in Figure 30

In addition to the above printed output, the present model is programmed to punch out an abbreviated daily summary in card format. This particular form of output is convenient for those using other computer programs to analyze the simulation output data since it makes manual transfer of the data from printed form to punched form unnecessary.

Appendix B contains a complete program listing for the close air support simulation program. The particular version of SIMSCRIPT used for the study was SIMSCRIPT 1.5 which runs under the control of the SCOPE operating system on the Control Data Corporation 6600 computer at Wright-Patterson Air Force Base, Ohio. The procedure for running the

```
DAY SORTIES GENERATED AT  88. 0. 0,TOTAL= 36
           TARGET TYPE        NUMBER
                1               7
                2               7
                3               4
                4               7
                5               6
                6               5



SUMMARY REPORT FOR DAY 89. 0. 0
                                TYPE 1             TYPE 2
AIRCRAFT DAMAGED TODAY              0                  2
AIRCRAFT DAMAGED TOTAL              0                283
AVIONIC FAILURES TODAY              0                  8
AVIONIC FAILURES TOTAL              0                819
AIRCRAFT KILLED TODAY               0                  1
AIRCRAFT KILLED TOTAL               0                216
CUM AVERAGE REPAIR TIME           0.0             18.140
CUM AVE AVIONIC REPAIR TIME       0.0              2.832
TOTAL SORTIES FLOWN TODAY =        44
TYPE 1 AIRCRAFT AVAILABLE AT END OF DAY=     0
TYPE 2 AIRCRAFT AVAILABLE AT END OF DAY=    17

                              TYPE  1     2     3     4     5     6
TARGETS DESTROYED TODAY             5     6     4     5     5     4      31
TARGETS DESTROYED TOTAL           326   447   422   465   486   478
EXCHANGE RATIO (TARGETS/AIRCRAFT) =     12.1481

WEATHER STATE       PERCENT TODAY       CUM PERCENT
      1                 0.0               0.0323
      2                 0.0               0.0117
      3                 0.0               0.0211
      4                 0.0               0.0290
      5                 0.0417            0.0375
      6                 0.0               0.0445
      7                 0.0               0.0431
      8                 0.9583            0.3455
      9                 0.0               0.2701
     10                 0.0               0.1653
```

Figure 29   Daily Summary Printout

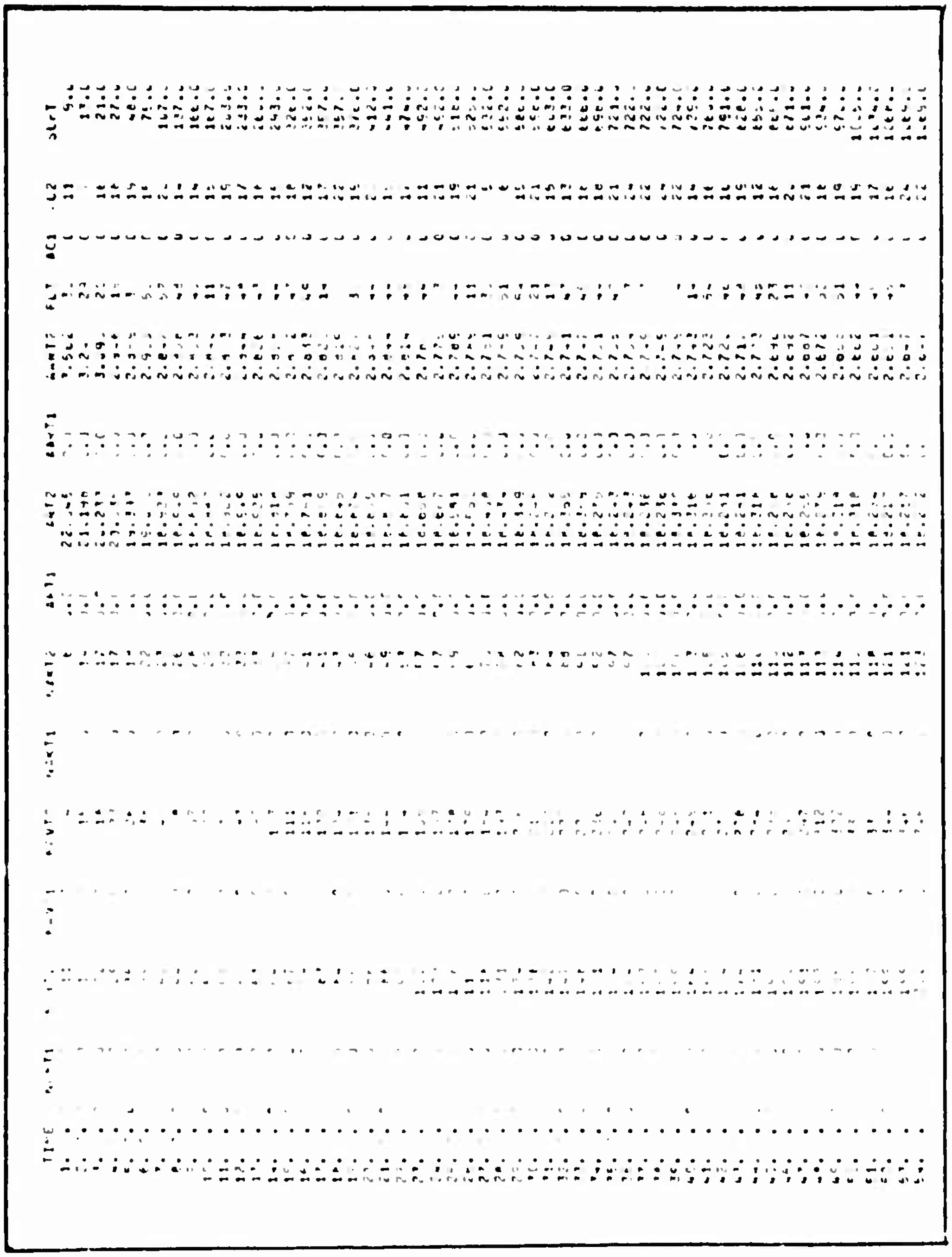

Figure 30 Daily Summary Printout (Table Form)

Reproduced from best available copy.

```
0. 1     SORTIE   1 FILED IN TASC
0. 1     AC  2 ASSIGNED AS 2ND CHOICE, SORTIE   1
0.40     AC  2 SURVIVES FEBA ON SORTIE   1
1. 0     WEATHER CHANGES FROM 10 TO  9
1. 0     AC 2 KILLS TARGET ON SORTIE   1
1. 0     AC 2 RETURNS TO BASE TO REFUEL
1.30     AC 2 REFUELS, TIME =    1.20000000
2. 0     WEATHER CHANGES FROM  9 TO  8
2.42     AC 2 RETURNED TO LINE, TOTAL NOW = 24
2.51     SORTIE   2 FILED IN TASC
2.51     AC  2 ASSIGNED AS 2ND CHOICE, SORTIE   2
3. 0     WEATHER CHANGES FROM  8 TO  8
3.31     AC  2 SURVIVES FEBA ON SORTIE   2
3.51     AC 2 KILLS TARGET ON SORTIE   2
3.51     AC 2 RETURNS TO BASE TO REFUEL
4. 0     WEATHER CHANGES FROM  8 TO  8
4.21     AC 2 REFUELS, TIME =    1.20000000
5. 0     SORTIE   3 FILED IN TASC
5. 0     AC  2 ASSIGNED AS 2ND CHOICE, SORTIE   3
5. 0     WEATHER CHANGES FROM  8 TO  8
5.19     SORTIE   4 FILED IN TASC
5.19     AC  2 ASSIGNED AS 1ST CHOICE, SORTIE   4
5.33     AC 2 RETURNED TO LINE, TOTAL NOW = 22
5.39     AC  2 SURVIVES FEBA ON SORTIE   3
5.59     AC 2 KILLS TARGET ON SORTIE   3
5.59     AC 2 RETURNS TO BASE TO REFUEL
5.59     AC  2 SURVIVES FEBA ON SORTIE   4
6. 0     WEATHER CHANGES FROM  8 TO  8
6. 3     SORTIE   5 FILED IN TASC
6. 3     AC  2 ASSIGNED AS 1ST CHOICE, SORTIE   5
6.19     AC 2 KILLS TARGET ON SORTIE   4
6.19     AC 2 RETURNS TO BASE TO REFUEL
6.29     AC 2 REFUELS, TIME =    1.20000000
```

Figure 31 Event List Printout

simulation model consisted of using the SIMSCRIPT 1.5 compiler to prepare COMPASS code which is, in turn, assembled into machine language by the COMPASS assembler. The approximate compilation time for the program used in this study was sixty seconds of central processor time while the running time for a typical simulation of ninety days of war was twenty seconds of central processor time.

Input data to be supplied by the model user is listed in Table 6. This data is contained in the initialization cards found at the end of the deck. Other variables contained in the initialization deck, but not described in Table 6, are used as counters for the output statistics and should not be modified by the program user.

The basic deck structure, as set up for the Control Data Corporation 6600 computer at Wright-Patterson Air Force Base, consists of several system control cards followed by the program source deck and an initialization deck for each case to be run. The following example illustrates a typical deck structure.

```
Job Card
NOREDUCE.
SIMS.
COMPASS (I=MAPTP, L=0, B=PUNCHB)
PUNCHB.
DISPOSE (TAPE9,PU)  <-------- May be eliminated if no punched
7/8/9                         output is desired.

  Program Source Deck

7/8/9

  Initialization Deck for Case 1

7/8/9

  Initialization Deck for Case 2

7/8/9
          .
          .
          .
7/8/9
```

Initialization Deck for Case n

7/8/9

6/7/8/9 End of Job Card

The format of each initialization deck should follow that presented in Figures 32, 33, 34, and 35.

At the beginning of each initialization deck should be a single system specification card. The contents of this card are shown below:

Card Columns	Entry
1-2	1x
11-12	80
17-18	60
23-24	24
25	1 If additional cases are to be run after this deck
	Blank If this is the last case to be run
35-36	60
41-42	60
47-48	61
53-54	55

Although the system control cards may vary slightly on other computers, the basic structure of the card deck should remain similar to the one shown above.

Variable Name	Definition	Function
SVFB	Prob. of aircraft surviving area defenses	Aircraft type Weather State
DVFB	Prob. that aircraft is damaged (not killed) given that it is hit by area defenses	Aircraft type
NFAC	0 = sortie cannot be flown without a FAC 1 = sortie can be flown without a FAC	Aircraft type Target type
FAC	Prob. of a FAC being available at target site	Target type
SVT2	Prob. of aircraft type 2 surviving target defenses	Target type Weather State
SVT1	Prob. of aircraft type 1 surviving target defenses	Target type Weather State
DVT	Prob. that aircraft is damaged (not killed) given that it is hit by target defenses	Target type
PKT2	Prob. of aircraft type 2 killing target on single pass	Target type Weather State
PKT1	Prob. of aircraft type 1 killing target on single pass	Target type Weather State
AC	Number of aircraft in the squadron (initial)	Aircraft type
A	10x10 transition matrix for the 10 weather states in the Markov process	
TARG	Time for the aircraft to fly from FEBA to target area	
RET	Time for the aircraft to return from target area to the forward airbase	
STID	Initial sortie identification number (usually)	

Table 6 Close Air Support Model Inputs

Variable Name	Definition	Function of
WST	Initial weather state	
REAC	Time for the aircraft to warm up, taxi, takeoff, and fly to the FEBA	
NST1	Initial No. of sorties flown by aircraft type 1 before the first avionic failure	
NST2	Initial No. of sorties flown by aircraft type 2 before the first avionic failure	
MTBF1	Mean No. of sorties flown between avionic failures for aircraft type 1	
MTBF2	Mean No. of sorties flown between avionic failures for aircraft type 2	
MTBA1	Mean repair time for avionic failures in type 1 aircraft	
MTBA2	Mean repair time for avionic failures in type 2 aircraft	
MTB1	Mean repair time for battle damage in type 1 aircraft	
MTB2	Mean repair time for battle damage in type 2 aircraft	
RFL1	Refueling and reloading time for aircraft type 1	
RFL2	Refueling and reloading time for aircraft type 2	
NHRS	Number of hours the simulation is to run	
IWRIT	1 = print out summary shown in Figure A-2 2 = print out event list shown in Figure A-4 3 = print out summary shown in Figure A-3	

Table 6 Close Air Support Model Inputs (Continued)

Variable Name	Definition	Function of
NUMB1	No. of sortie requests/day from 2400 to 600 hrs	
NUMB2	No. of sortie requests/day from 600 to 1200 hrs	
NUMB3	No. of sortie requests/day from 1200 to 1800 hrs	
NUMB4	No. of sortie requests/day from 1800 to 2400 hrs	
ISEED	An odd integer used as the seed value for the random number generator in the model	

Table 6 Close Air Support Model Inputs (Continued)

All time estimates except NHRS are input in the dimension of fractional days. For example, one hour would be input as 0.0416667 days.

CLOSE AIR SUPPORT SIMULATION INITIALIZATION DECK 1 4

FORTRAN STATEMENT

1	4	0	2								QUEUES
5		0	R						2		SVFBR
6		0	R						10		SVFBC
7		2	R	2	5	10	6	R N	10(DI.3)		SVFB
INSERT 2 CARDS WITH 10(DI.3) FORMAT											
8		0	R						2		DVFBC
9		1	R	2	8				2(DI.3)		DVFB
INSERT 1 CARD WITH 2(DI.3) FORMAT											
10		0	R						2		NFACR
11		0	R						6		NFACC
12		2	R	2	10	6	11	R N	6(I2)		NFAC
INSERT 2 CARDS WITH 6(I2) FORMAT											
13		0	R						6		FACC
14		1	R	6	13				6(DI.3)		FAC
INSERT 1 CARD WITH 6(DI.3) FORMAT											
15		0	R						2		KACC
16		1	2	2	15						KAC
17		0	R						6		SVT2R
18		0	R						10		SVT2C
19		2	R	6	17	10	18	R N	10(DI.3)		SVT2
INSERT 6 CARDS WITH 10(DI.3) FORMAT											
20		0	R						6		SVT1R
21		0	R						10		SVT1C
22		2	R	6	20	10	21	R N	10(DI.3)		SVT1

Figure 32 Initialization Deck Coding Sheet Page 1 of 4

CLOSE AIR SUPPORT SIMULATION INITIALIZATN DECK — 2 4

FORTRAN STATEMENT

	← INSERT 6 CARDS WITH 10(D1.3) FORMAT →							
23	0 R						6	DVTC
24	1 R	6	23				6(D1.3)	DVT
	← INSERT 1 CARD WITH 6(D1.3) FORMAT →							
25	0 R						6	PKT2R
26	0 R						10	PKT2C
27	2 R	6	25	10	26	R N	10(D1.3)	PKT2
	← INSERT 6 CARDS WITH 10(D1.3) FORMAT →							
28	0 R						6	PKT1R
29	0 R						10	PKT1C
30	0 R	6	28	10	29	R N	10(D1.3)	PKT1
	← INSERT 6 CARDS WITH 10(D1.3) FORMAT →							
31	0 R						6	NTKLC
32	1 2	6	31					NTKL
33	0 R						2	ACC
34	1 R	2	33				2(I5)	AC
	← INSERT 1 CARD WITH 2(I5) FORMAT →							
35	0 R						10	AROW
36	0 R						10	ACOL
37	2 R	10	35	10	36	R N	10(D1.3)	A
	← INSERT 10 CARDS WITH 10(D1.3) FORMAT →							
38	0 R						(PLACE VALUE HERE)	TARG
39	0 R						(PLACE VALUE HERE)	RET
40	0 R						(PLACE VALUE HERE)	STID

Figure 33 Initialization Deck Coding Sheet Page 2 of 4

CLOSE AIR SUPPORT SIMULATION INITIALIZATION DECK

PUNCHING INSTRUCTIONS	GRAPHIC		PAGE	3 OF 4
DATE	PUNCH			

FORTRAN STATEMENT

41		O	R			(PLACE VALUE HERE)	WST
42		O	R			(PLACE VALUE HERE)	REAC
43		C	R			(PLACE VALUE HERE)	NST1
44		O	R			(PLACE VALUE HERE)	NST2
45		O	R			(PLACE VALUE HERE)	MTBF1
46		O	R			(PLACE VALUE HERE)	MTBF2
47		C	R			(PLACE VALUE HERE)	MTBA1
48		O	R			(PLACE VALUE HERE)	MTBA2
49		O	R			(PLACE VALUE HERE)	MTB1
50		O	R			(PLACE VALUE HERE)	MTB2
51		O	R			(PLACE VALUE HERE)	RFL1
52		O	R			(PLACE VALUE HERE)	RFL2
53		C	R			(PLACE VALUE HERE)	NHRS
54		C	R			(PLACE VALUE HERE)	IWRIT
55	68	C	2				IDS
69		O	R			6	TTKLC
70		1	.2	6	69		TTKL
71		O	R			10	ITWSC
72		1	2	10	71		ITWST
73		C	R			20	CTWSC
74		1	2	10	73		CTWST
75		O	R			(PLACE VALUE HERE)	NUMB1
76		O	R			(PLACE VALUE HERE)	NUMB2
77		C	R			(PLACE VALUE HERE)	NUMB3

Figure 34 Initialization Deck Coding Sheet Page 3 of 4

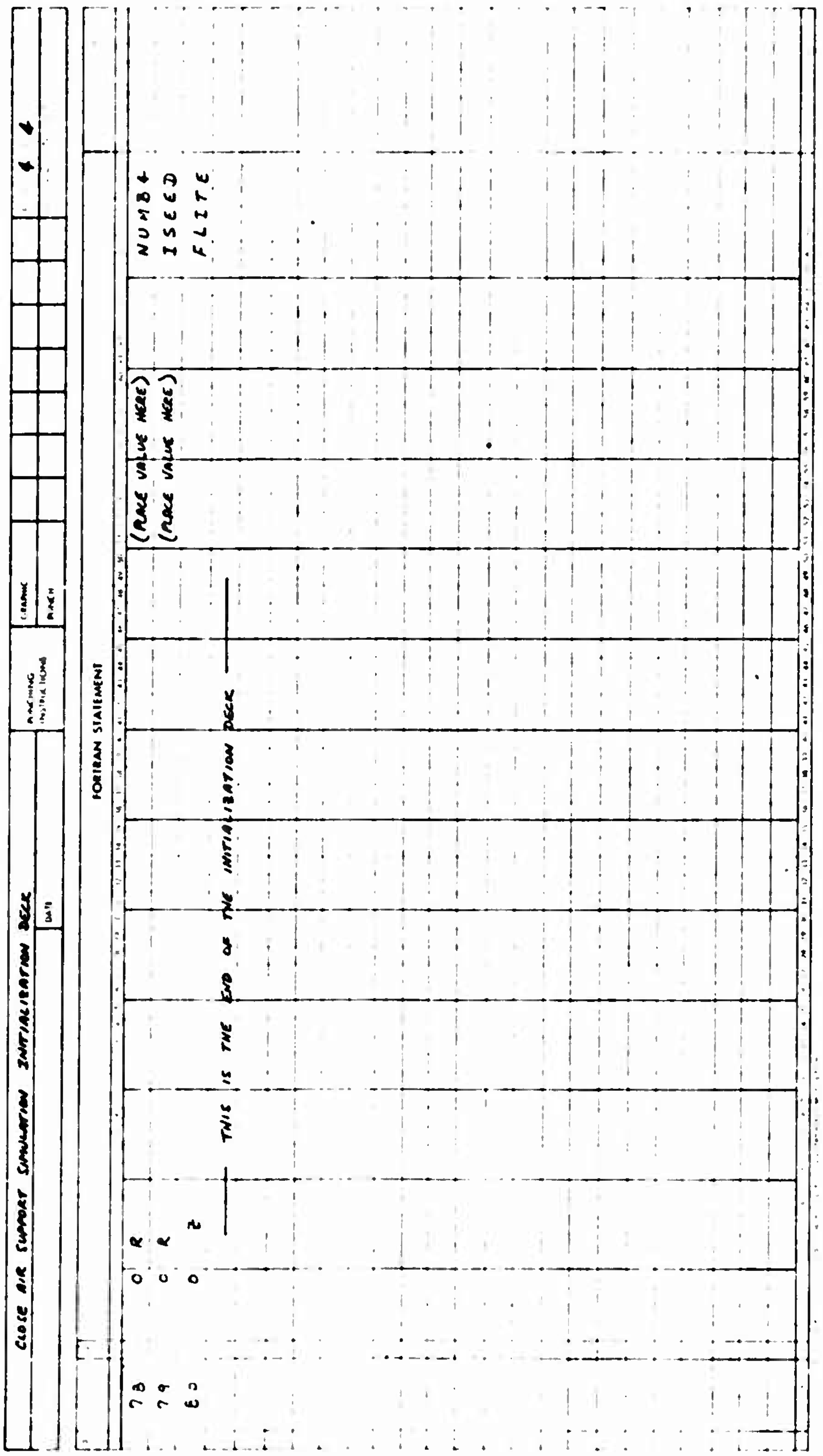

Figure 35 Initialization Deck Coding Sheet Page 4 of 4

APPENDIX B

CLOSE AIR SUPPORT COMPUTER PROGRAM LISTING

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$

               6C00 SIMSCRIPT   VERSION 2.1     MARCH 1970
         DEFINITION CARDS
         0         1         2         3         4         5         6         7         8
COLUMN   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345678

         *T SCRT 8         T TYPE  1     I  1FTASC 0    I     TASC   XSORTE L
         *                 T LIFE  2     F  2LTASC 0    I
         *                 T MXCD1 3     I  3FTMFL 0    I     TMFL  X
         *                 T MXCD2 4     I  4LTMFL 0    I
         *                 T SORTE 5     F  5 STAR 0    IX
         *                 T ID    6     I  6SVFBC 0    IX
         *                 T STASC 7     I  7SVFB  2    FX
         *                 T PTASC 8     I  8LVFBC 0    IX
         *                 T STMFL 7     I
         *N FERA 8         N SXT   3     I  9OVFB  1    FX
         *                 N ITP   4     I 10NFACR C    IX
         *                 N MX    5     I 11MFACC 0    IX
         *N ARRIV8         N ST    3     I 12FFAC  2    IX
         *                 N ITY   4     I 13FACC  0    IX
         *                 N M     5     I 14FAC   1    IX
         *N REPWA4         N IX*   3     I 15FACC  0    IX
         *N REPF 4         N IX    3     I 16FAC   1    I
         *N REPLC4         N I     3     I 17SVT2R C    IX
         *N TESTM2                          18SVT2C 0    IX
         *N MEFUL4                          19SVT2  2    FX
         *N ENDSM2                          20SVT1R C    IX
         *N DAYMF2                          21SVT1C 0    IX
         *N LIST 2                          22SVT1  2    FX
         *N RECST4         N ITMAG 3     I  23SVTC 0    IX
         *                                  24SVT   1    FX
         *                                  25PKT2R 0    IX
         *                                  26PKT2C 0    IX
         *                                  27PKT2  2    FX
         *                                  28PKT1R 0    IX
         *                                  29PKT1C 0    IX
         *                                  30PKT1  2    FX
         *                                  31NTKLC 0    IX
         *                                  32NTKL  1    I
         *                                  33ACC   0    IX
         *                                  34AC    1    I
         *                                  35APOW  0    IX
         *                                  36ACOL  0    IX
         *                                  37A     2    FX
         *                                  38TARG  0    FX
         *                                  39DRT   0    FX
         *                                  40STID  0    I
         *                                  41MST   0    I
         *                                  42PFAC  0    FX
         *                                  43NGT1  0    I
         *                                  44NGT2  0    I
         *                                  45MTGF1 0    FX
         *                                  46MTGF2 0    FX
         *                                  47MTBA1 0    FX
         *                                  48MTBA2 0    FX
         *                                  49MTR1  0    FX
         *                                  50MTR2  0    FX
         *                                  51MFL1  0    FX
         *                                  52MFL2  0    FX
         *                                  53NMPS  0    FX
         *                                  54IMRIT 0    IX
         *                                  55NCM1  0    I
         *                                  56NCM2  0    I
         *                                  57NCMT1 0    I
```

•	58NOMT2	0	I
•	59NAKT1	0	I
•	60NAKT2	0	I
•	61NAV1	0	I
•	62NAV2	0	I
•	63NAVT1	0	I
•	64NAVT2	0	I
•	65TRT1	0	F
•	66TRT2	0	F
•	67TAWT1	0	F
•	68TAWT2	0	F
•	69TTKLC	0	I*
•	70TTKL	1	I
•	71ITHSC	0	I*
•	72ITHST	1	I
•	73CTHSC	0	I*
•	74CTHST	1	F
•	75NUMB1	0	I*
•	76NUMB2	0	I*
•	77NUMB3	0	I*
•	78NUMB4	0	I*
•	79ISCHO	0	I*
•	80FLITE	0	I

```
EVENTS
1 EXOGENOUS
   WTHR   (1)
11 ENDOGENOUS
   LIST
   REQST
   FERA
   ARRIV
   REFWA
   REPR
   REPUL
   REPLC
   TESTW
   ENDSW
   DAYWW
END
```

```
      EXOGENOUS EVENT WTHR
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
C     THIS EVENT IS THE OVERALL CONTROLLING EVENT FOR THE SIMULATION.
C     IT GENERATES THE EVENT TESTW AT ONE HOUR INTERVALS AND THEN
C     GENERATES THE END OF SIMULATION EVENT CALLED ENDSM.
      LET RANDR=ISEED
      LET DWT=0.0
      LET INHRS=NHRS-1.0
      LET NHRS=NHRS/24.0
      DO,FOR J=(1)(INHRS)
      LET DWT=DWT+0.04166667
      CREATE TESTW
      CAUSE TESTW AT TIME + DWT
      LOOP
      LET INHRS=NHRS
      LET DLIST=0.0
      DO,FOR K=(1)(INHRS)
      CREATE LIST
      CAUSE LIST AT TIME + DLIST + 1.0/1440.0
      LET DLIST=DLIST+1.0
      LOOP
      LET DR=0.0
      DO,FOR K=(1)(INHRS)
      LET DR=DR+1.0
      CREATE DAYRP
      CAUSE DAYRP AT TIME + DR
      LOOP
      LET ITWST(WST)=ITWST(WST)+1
      CREATE ENDSM
      CAUSE ENDSM AT TIME + NHRS
         WRITE ON 61
      FORMAT(*1                    CLOSE AIR SUPPORT SIMULATION*)
      WRITE ON 61
      FORMAT(S18,*DEVELOPED BY D.K. LEEDOM*)
      WRITE ON 61
      FORMAT(S18,*AFIT/ENS (GSA-73)   23 JAN 73*)
      WRITE ON 61
      FORMAT(/S10,*SWFR    IAC=ROWS    IWX=CCLUMNS*)
      DO,FOR K=(1)(2)
      WRITE ON 61,SWFR(K,KC), FOR KC=(1)(13)
      FORMAT 13(S5,D1.3)
      LOOP
      WRITE ON 61
      FORMAT(/S10,*DWFR    IAC=ROWS*)
      DO,FOR K=(1)(2)
      WRITE ON 61,DWFR(K)
      FORMAT(S10,D1.3)
      LOOP
      WRITE ON 61
      FORMAT(/S10,*NFAC    IAC=ROWS    TYPE(SORT)=CCLUMNS*)
      DO,FOR K=(1)(2)
      WRITE ON 61,NFAC(K,KC), FOR KC=(1)(6)
      FORMAT 6(S5,I3)
      LOOP
      WRITE ON 61
      FORMAT(/S10,*FAC    TYPE(SORT)=ROWS*)
      DO,FOR K=(1)(6)
      WRITE ON 61,FAC(K)
      FORMAT(S10,D1.3)
      LOOP
```

```
WRITE ON 61
FORMAT(/S10,*SVT2   TYPE(SORT)=ROWS   IWX=COLUMNS*)
DO,FOR K=(1)(6)
WRITE ON 61,SVT2(K,KC), FOR KC=(1)(10)
FORMAT 10(S5,D1.3)
LOOP
WRITE ON 61
FORMAT(/S10,*SVT1   TYPE(SORT)=ROWS   IWX=COLUMNS*)
DO,FOR K=(1)(6)
WRITE ON 61,SVT1(K,KC), FOR KC=(1)(10)
FORMAT 10(S5,D1.3)
LOOP
WRITE ON 61
FORMAT(/S10,*SVT   TYPE(SORT)=ROWS )
DO,FOR K=(1)(6)
WRITE ON 61,SVT(K)
FORMAT(S10,D1.3)
LOOP
WRITE ON 61
FORMAT(/S10,*PKT2   TYPE(SORT)=ROWS   IWX=COLUMNS*)
DO,FOR K=(1)(6)
WRITE ON 61,PKT2(K,KC), FOR KC=(1)(10)
FORMAT 10(S5,D1.3)
LOOP
WRITE ON 61
FORMAT(/S10,*PKT1   TYPE(SORT)=ROWS   IWX=COLUMNS*)
DO,FOR K=(1)(6)
WRITE ON 61,PKT1(K,KC), FOR KC=(1)(10)
FORMAT 10(S5,D1.3)
LOOP
WRITE ON 61
FORMAT(/S10,*AC   IAC=ROWS*)
DO,FOR K=(1)([illegible])
WRITE ON 61,AC(K)
FORMAT(S10,I5)
LOOP
WRITE ON 61
FORMAT(/S10,*A   WST=ROWS   N=COLUMNS*)
DO,FOR K=(1)(10)
WRITE ON 61,A(K,KC), FOR KC=(1)(10)
FORMAT 10(S5,D1.4)
LOOP
WRITE ON 61,TARC
FORMAT(S10,*TARC=*,M3,* MINS*)
WRITE ON 61,RET
FORMAT(S10,*RET =*,M3,* MINS*)
WRITE ON 61,REAC
FORMAT(S10,*REAC=*,M3,* MINS*)
WRITE ON 61,WST
FORMAT(S10,*WST =*,I3)
WRITE ON 61,MTSC1
FORMAT(S10,*MTSC1=*,D3.4,* SORTIES*)
WRITE ON 61,MTSC2
FORMAT(S10,*MTSC2=*,D3.4,* SORTIES*)
WRITE ON 61,MTRS1
FORMAT(S10,*MTRS1=*,M3.4,* HRS*)
WRITE ON 61,MTRS2
FORMAT(S10,*MTRS2=*,M3.4,* HRS*)
WRITE ON 61,MT41
FORMAT(S10,*MT41 =*,M3.4,* HRS*)
WRITE ON 61,MT42
FORMAT(S10,*MT42 =*,M3.4,* HRS*)
WRITE ON 61,PFL1
FORMAT(S10,*PFL1 =*,M3,* MINS*)
WRITE ON 61,PFL2
FORMAT(S10,*PFL2 =*,M3,* MINS*)
```

```
      WRITE ON 61,NHRS
      FORMAT(S1J,*NHRS =*,M6.J,* HRS*)
      WRITE ON 61,NUMR1
      FORMAT(S1J,*NUMR1=*,I3,* SORTIES*)
      WRITE ON 61,NUMR2
      FORMAT(S1J,*NUMR2=*,I3,* SORTIES*)
      WRITE ON 61,NUMR3
      FORMAT(S1J,*NUMR3=*,I3,* SORTIES*)
      WRITE ON 61,NUMR4
      FORMAT(S1J,*NUMR4=*,I3,* SORTIES*)
      IF(IWRIT)EQ(2),WRITE ON 61,NHRS
      FORMAT(S5,*HRS.MINS*,S1J,*EVENT*,S2J,*SIMULATION TIME = *,M3.2/)
      IF(IWRIT)EQ(4),WRITE ON 61
      FORMAT(*     TIME    NUMT1    NUMT2    NAVT1    NAVT2    NAKT1    NAKT2*,
     1*    ARI1    ARI2    AART1    AART2  FLT  AC1  AC2     SUMT*)
      RETURN
      END
```

```
      ENDOGENOUS EVENT LIST
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
C     THIS EVENT CREATES A RANDOM LIST OF (NUMB) SORTIES AT THE
C     BEGINNING OF EACH SIMULATED DAY.
      DIMENSION NTRG(6)
      LET NUMB=NUMB1+NUMB2+NUMB3+NUMB4
      IF(IWRITE)EQ(1),WRITE ON 61,TIME,NUMB
      FORMAT(*1*//S10,*DAY SORTIES GENERATED AT *,F3.2.2,*,TOTAL=*,I3)
      DO,FOR K=(1)(6)
      LET NTRG(K)=0
      LOOP
      DO,FOR K=(1)(NUMB1)
      LET SRTM=RANDI(1,720)
      CREATE REQST
      LET ITARG(REQST)=RANDI(1,6)
      LET NTRG(ITARG(REQST))=NTRG(ITARG(REQST))+1
      CAUSE REQST AT TIME + (SRTM-1.0)/1440.0
      LOOP
      LET NUMBX=[illegible]
      DO,FOR K=(1)(NUMX)
      LET SRTM=RANDI(1,720)
      CREATE REQST
      LET ITARG(REQST)=RANDI(1,6)
      LET NTRG(ITARG(REQST))=NTRG(ITARG(REQST))+1
      CAUSE REQST AT TIME + (SRTM+359.0)/1440.0
      LOOP
      DO,FOR K=(1)(NUMB4)
      LET SRTM=RANDI(1,360)
      CREATE REQST
      LET ITARG(REQST)=RANDI(1,6)
      LET NTRG(ITARG(REQST))=NTRG(ITARG(REQST))+1
      CAUSE REQST AT TIME + (SRTM+1079.0)/1440.0
      LOOP
      IF(IWRITE)EQ(1),WRITE ON 61
      FORMAT(S10,*TARGET TYPE        NUMBER*)
      DO,FOR K=(1)(6)
      IF(IWRITE)EQ(1),WRITE ON 61,K,NTRG(K)
      FORMAT(S17,I1,S9,I3)
      LOOP
      DESTROY LIST
      RETURN
      END
```

```
      ENDOGENOUS EVENT REQST
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
C     THIS EVENT MARKS THE GENERATION OF A SORTIE REQUEST.  ALL NEW
C     SORTIE REQUESTS ARE FILED IN A QUEUE NAMED TASC WHICH RANKS THEM
C     BY THEIR TIME OF EXPIRATION.  SUBROUTINE DSPCH IS ALSO CALLED TO
C     SEE IF THE NEW SORTIE CAN BE MATCHED WITH AVAILABLE AIRCRAFT.
      CREATE SORT
      LET TYPE(SORT)=ITARG(REQST)
      GO TO (10,[illegible],50,60), ITARG(REQST)
   10 LET LIFE(SORT)= [illegible]/1440.0
      LET W*CD1(SORT)=1111111110
      LET W*CD2(SORT)=[illegible]
      GO TO 70
   20 LET LIFE(SORT)= [illegible]/1440.0
      LET W*CD1(SORT)=1111111110
      LET W*CD2(SORT)=2222222220
      GO TO 70
   30 LET LIFE(SORT)= 75.0/1440.0
      LET W*CD1(SORT)=[illegible]1110
      LET W*CD2(SORT)=0110110[illegible]0
      GO TO 70
   40 LET LIFE(SORT)= [illegible]/1440.0
      LET W*CD1(SORT)=2222221110
      LET W*CD2(SORT)=01101192 0
      GO TO 70
   50 LET LIFE(SORT)=1[illegible].0/1440.0
      LET W*CD1(SORT)=2222221110
      LET W*CD2(SORT)=[illegible]11[illegible]110220
      GO TO 70
   60 LET LIFE(SORT)=1[illegible].0/1440.0
      LET W*CD1(SORT)=2222221110
      LET W*CD2(SORT)=0110110220
   70 LET [illegible](SORT)=TIME+LIFE(SORT)
      LET I[illegible](SORT)=STIO
      FILE SORT IN TASC
      IF(IPRINT)[illegible],WRITE ON 61,TIME,STIO
      FORMAT([illegible],*SORTIE *,I3,* FILED IN TASC*)
      LET STIO=STIO+1
      CALL DSPCH
      DESTROY REQST
      RETURN
      END
```

```
      ENDOGENOUS EVENT FEBA
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
C     THIS EVENT TESTS THE ASSIGNED AIRCRAFT TO SEE WHETHER OR NOT IT
C     SURVIVES THE AREA DEFENSES.  IF IT SURVIVES, THEN EVENT ARRIV IS
C     CAUSED AT TIME + TARG.  IF IT DOES NOT SURVIVE THEN EITHER EVENT
C     REPR OR EVENT REFIL IS CAUSED AT TIME + RET OR TIME + 1/2 DAY.
      LET [illegible]
      STORE [illegible] IN SORT
      LET IAC=IT [illegible]
      LET [illegible]
      LET [illegible]
C     CHECK TO SEE IF AIRCRAFT IS HIT
      LET [illegible] (IAC,I[illegible])
      IF([illegible]) [illegible] 10
C     AIRCRAFT IS HIT
      FILE [illegible] IN TAC
      LET [illegible](IAC)
C     CHECK TO SEE IF AIRCRAFT IS KILLED OR DAMAGED
      LET [illegible]
      IF([illegible]) [illegible] 20
C     AIRCRAFT IS KILLED
      IF(I[illegible]),WRITE ON 61,TIME,IAC,ID(SORT)
      FORMAT([illegible],*AC *,I2,* KILLED AND SORTIE *,I3,* REFILED*)
      LET [illegible](IAC)-1
      CREATE REFIL
      LET I[illegible]=IAC
      CAUSE REFIL AT TIME+0.5
C     CHECK TO SEE IF SORTIE CAN BE REASSIGNED
      CALL [illegible]
C     INDEX THE AVION SUBROUTINE BY ONE SORTIE
      CALL AVION([illegible],IAC)
      GO TO [illegible]
   10 CREATE ARRIV
C     AIRCRAFT SURVIVES AREA DEFENSES
      STORE [illegible] IN S(ARRIV)
      LET IT(ARRIV)=IAC
      LET [illegible](ARRIV)=[illegible]
      CAUSE ARRIV AT TIME+TARG
      IF(I[illegible]),WRITE ON 61,TIME,IAC,ID(SORT)
      FORMAT([illegible],*AC *,I2,* SURVIVES FEBA ON SORTIE *,I3)
      GO TO [illegible]
   20 CREATE REPR
C     AIRCRAFT IS DAMAGED
      IF(I[illegible]),WRITE ON 61,TIME,IAC,ID(SORT)
      FORMAT([illegible],*AC *,I2,* DAMAGED AND SORTIE *,I3,* REFILED*)
      LET I[illegible](REPR)=IAC
      CAUSE REPR AT TIME+RET
C     CHECK TO SEE IF SORTIE CAN BE REASSIGNED
      CALL [illegible]
C     INDEX THE AVION SUBROUTINE BY ONE SORTIE
      CALL AVION([illegible],IAC)
   30 DESTROY FEBA
      RETURN
      END
```

```
      ENDOGENOUS EVENT ARRIV
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
C     THIS EVENT SIMULATES THE AIRCRAFT OPERATING IN THE TARGET AREA.
      STORE ST(ARRIV) IN SORT
      LET IAC=ITY(ARRIV)
      LET INT=M(ARRIV)
      LET R=RANDM
      LET FC=FAC(TYPE(SORT))
C     CHECK TO SEE IF FORWARD AIR CONTROLLER IS AVAILABLE
      IF(RDLE(FC),GO TO 100
      LET NOFAC=NFAC(IAC,TYPE(SORT))
C     FAC NOT AVAILABLE, CHECK TO SEE IF SORTIE CAN BE FLOWN W/O FAC
      IF(NOFAC)EQ(1),GO TO 100
C     FAC NOT AVAILABLE, SORTIE CANNOT BE COMPLETED
      FILE SORT IN TARL
      IF(IWRITE)EQ(1),WRITE ON 61,TIME,ID(SORT)
      FORMAT(S4,F7.2,S4,*FAC NOT AVAILABLE AND SORTIE *,I3,* REFILED*)
C     AIRCRAFT RETURNS TO BASE, TEST AREA DEFENSES VIA RETURN
      LET R=RANDM
      LET PR=SPRE(IAC,14)
C     CHECK TO SEE IF AIRCRAFT HIT
      IF(R)LE(PR),GO TO 10
C     AIRCRAFT HIT
      LET PR=PK(IAC)
C     CHECK TO SEE WHETHER AIRCRAFT KILLED OR DAMAGED
      LET R=RANDM
      IF(R)LE(PR),GO TO 10
C     AIRCRAFT KILLED, CAUSE REPLC AT TIME + 1/2 DAY
      IF(IWRITE)EQ(1),WRITE ON 61,TIME,IAC
      FORMAT(S4,F7.2,S4,*AC *,I2,* KILLED ON RETURN*)
      LET KAC(IAC)=KAC(IAC)+1
      CREATE REPLC
      LET I(REPLC)=IAC
      CAUSE REPLC AT TIME + 0.5
C     SEE IF SORTIE CAN BE REASSIGNED
      CALL DSPCH
C     INDEX THE AVION SUBROUTINE BY ONE SORTIE
      CALL AVION(IFAIL,IAC)
      DESTROY ARRIV
      RETURN
C     AIRCRAFT NOT HIT ON RETURN TO BASE
   10 CALL AVION(IFAIL,IAC)
C     CHECK FOR AVIONIC FAILURE
      IF(IFAIL)EQ(1),GO TO 20
C     AVIONICS OPERATING, CAUSE REFUELING AT TIME + RET
      IF(IWRITE)EQ(1),WRITE ON 61,TIME,IAC
      FORMAT(S4,F7.2,S4,*AC *,I2,* RETURNS TO BASE TO REFUEL*)
      CREATE REFUL
      LET IR(REFUL)=IAC
      CAUSE REFUL AT TIME + RET
C     SEE IF SORTIE CAN BE REASSIGNED
      CALL DSPCH
      DESTROY ARRIV
      RETURN
C     AVIONICS FAILED, CAUSE REPRA AT TIME + RET
   20 CREATE REPRA
      LET IRA(REPRA)=IAC
      CAUSE REPRA AT TIME + RET
      IF(IWRITE)EQ(1),WRITE ON 61,TIME,IAC
      FORMAT(S4,F7.2,S4,*AC *,I2,* RETURNS WITH AVIONIC FAILURE*)
```

```
      CALL DSFCH
      DESTROY ARRIV
      RETURN
C     AIRCRAFT DAMAGED, CAUSE REPR AT TIME + RETURN TIME
      IF(IWRIT)EQ(2),WRITE ON 61,TIME,IAC
      FORMAT(S*,M7.2,C4,*AC *,I2,* RETURNS TO BASE DAMAGED*)
   30 CREATE REPR
      LET IR(REPR)=IAC
      CAUSE REPR AT TIME + RET
C     SEE IF SORTIE CAN BE REASSIGNED
      CALL DSFCH
C     INDEX THE AVION SUBROUTINE BY ONE SORTIE
      CALL AVION(IFAIL,IAC)
      DESTROY ARRIV
      RETURN
C     EITHER FAC AVAILABLE OR SORTIE CAN BE FLOWN W/O FAC
  100 IF(ID)EQ(1),GO TO 200
      CALL AVION(IFAIL,2)
C     CHECK STATUS OF AVIONICS
C               AIRCRAFT TYPE 2 AT TARGET AREA
      IF(IFAIL)EQ(1), GO TO 150
C     AVIONICS FAILED
      FILE EVENT IN TACC
      IF(IWRIT)EQ(2),WRITE ON 61,TIME,ID(SORT)
      FORMAT(S*,M7.2,C4,*AC 2 AVIONIC FAILURE, SORTIE *,I3,* REFILED*)
C     AIRCRAFT RETURNS TO BASE, TEST AGAINST AREA DEFENSES
      LET R=RANDM
      LET SP=SPWR(2,IN)
C     CHECK TO SEE IF AIRCRAFT HIT
      IF(R)LE(SP),GO TO 110
C     AIRCRAFT HIT
      LET PR=DWPR(2)
C     CHECK TO SEE WHETHER AIRCRAFT KILLED OR DAMAGED
      LET R=RANDM
      IF(R)LE(PR),GO TO 120
C     AIRCRAFT KILLED, CAUSE REPLC AT TIME + 1/2 DAY
      IF(IWRIT)EQ(2),WRITE ON 61,TIME
      FORMAT(S*,M7.2,C4,*AC 2 KILLED ON RETURN*)
      LET KAC(2)=KAC(2)+1
      CREATE REPLC
      LET IR(REPLC)=2
      CAUSE REPLC AT TIME + 0.5
C     SEE IF SORTIE CAN BE REASSIGNED
      CALL DSFCH
      DESTROY ARRIV
      RETURN
C     AIRCRAFT RETURNS TO BASE WITH AVIONIC FAILURE
  110 CREATE REPRA
      LET IRA(REPRA)=2
      CAUSE REPRA AT TIME + RET
      IF(IWRIT)EQ(2),WRITE ON 61,TIME
      FORMAT(S*,M7.2,C4,*AC 2 RETURNS WITH AVIONIC FAILURE*)
C     SEE IF SORTIE CAN BE REASSIGNED
      CALL DSFCH
      DESTROY ARRIV
      RETURN
C     AIRCRAFT DAMAGED, CAUSE REPR AT TIME + RETURN TIME
  120 CREATE REPR
      LET IR(REPR)=2
      CAUSE REPR AT TIME + RET
      IF(IWRIT)EQ(2),WRITE ON 61,TIME
      FORMAT(S*,M7.2,C4,*AC 2 RETURNS TO BASE DAMAGED*)
C     SEE IF SORTIE CAN BE REASSIGNED
      CALL DSFCH
      DESTROY ARRIV
      RETURN
```

```
C       AIRCRAFT ARRIVES FOR FIRST PASS AT TARGET
   150 LET K=1
   151 LET R=RANDOM
C       TEST AGAINST LOCAL TARGET DEFENSES
       LET SV=SVT2(TYPE(SORT),IWX)
       IF(R)GT(SV),GO TO 160
C       AIRCRAFT SURVIVES LOCAL DEFENSES ON THIS PASS
       LET FK=FKT2(TYPE(SORT),IWX)
C       TEST TO SEE IF TARGET IS KILLED
       LET R=RANDOM
       IF(R)LE(FK),GO TO 190
C       TARGET NOT KILLED, REATTACK?
       IF(IWRITE)EQ(2),WRITE ON 61,TIME
       FORMAT(S5,M7.2,S4,*AC 2 MAKES PASS, TARGET NOT KILLED*)
       LET K=K+1
C       CHECK NUMBER OF PASSES (ONLY TWO ALLOWED)
       IF(K)GE(3),GO TO 152
C       REATTACK TARGET
       GO TO 151
   152 FILE SORT IN TAR
       IF(IWRITE)EQ(2),WRITE ON 61,TIME,ID(SORT)
       FORMAT(S5,M7.2,S4,*2ND PASS BY AC 2, SORTIE *,I3, * REFILED*)
C       TWO PASSES MADE AND TARGET NOT KILLED
C       SEE IF SORTIE CAN BE REASSIGNED
       CALL DSRCH
       GO TO 191
   160 FILE SORT IN TARG
C       AIRCRAFT HIT
       LET CF=C.T(TYPE(SORT))
C       CHECK TO SEE WHETHER AIRCRAFT KILLED OR DAMAGED
       LET R=RANDOM
       IF(R)LT(CF),GO TO 170
C       AIRCRAFT KILLED. CAUSE REPLC AT TIME + 1/2 DAY
       IF(IWRITE)EQ(2),WRITE ON 61,TIME,ID(SORT)
       FORMAT(S5,M7.2,S4,*AC 2 KILLED AT TARGET, SORTIE *,I3,* REFILED*)
       LET KAC(2)=KAC(2)+1
       CREATE REPLC
       LET I(REPLC)=2
       CAUSE REPLC AT TIME + 0.5
C       SEE IF SORTIE CAN BE REASSIGNED
       CALL DSRCH
       DESTROY ARRIV
       RETURN
C       AIRCRAFT DAMAGED, CAUSE REPR AT TIME + RETURN TIME
   170 CREATE REPR
       LET IR(REPR)=2
       CAUSE REPR AT TIME + RET
       IF(IWRITE)EQ(2),WRITE ON 61,TIME,ID(SORT)
       FORMAT(S5,M7.2,S4,*AC 2 DAMAGED AT TARGET, SORTIE *,I3,* REFILED*)
C       SEE IF SORTIE CAN BE REASSIGNED
       CALL DSRCH
       DESTROY ARRIV
       RETURN
C       TARGET KILLED (SORTIE REQUEST FULFILLED)
   190 LET KTKL(TYPE(SORT))=KTKL(TYPE(SORT))+1
       IF(IWRITE)EQ(2),WRITE ON 61,TIME,ID(SORT)
       FORMAT(S5,M7.2,S4,*AC 2 KILLS TARGET ON SORTIE *,I3)
       DESTROY SORT
C       TEST AGAINST AREA DEFENSES ON RETURN TO BASE
   191 LET R=RANDOM
       LET SF=SVFF(2,IWX)
C       CHECK TO SEE IF AIRCRAFT HIT
       IF(R)LE(SF),GO TO 195
C       AIRCRAFT HIT
       LET CF=CVF2(2)
C       CHECK TO SEE IF AIRCRAFT KILLED OR DAMAGED
```

```
      LET R=RANDM
      IF(R)LE(PP),GO TO 190
C     AIRCRAFT KILLED, CAUSE REPLC AT TIME + 1/2 DAY
      IF(IWRIT)EQ(2),WRITE ON 61,TIME
      FORMAT(S5,F3.2,S4,*AC 2 KILLED ON RETURN TO BASE*)
      LET KAC(2)=KAC(2)+1
      CREATE REPLC
      LET I(REPLC)=2
      CAUSE REPLC AT TIME + 0.5
      DESTROY ARRIV
      RETURN
C     AIRCRAFT RETURNS UNDAMAGED TO BASE, CAUSE REFUL AT TIME + RET
  185 CREATE REFUL
      LET IK(REFUL)=2
      CAUSE REFUL AT TIME + RET
      IF(IWRIT)EQ(2),WRITE ON 61,TIME
      FORMAT(S5,F3.2,S4,*AC 2 RETURNS TO BASE TO REFUEL*)
      DESTROY ARRIV
      RETURN
C     AIRCRAFT DAMAGED, CAUSE REPR AT TIME + RET
  190 CREATE REPR
      LET IK(REPR)=2
      CAUSE REPR AT TIME + RET
      IF(IWRIT)EQ(2),WRITE ON 61,TIME
      FORMAT(S5,F3.2,S4,*AC 2 DAMAGED ON RETURN TO BASE*)
      DESTROY ARRIV
      RETURN
C              AIRCRAFT TYPE 1 AT TARGET AREA
  200 CALL AVION(IFAIL,1)
C     CHECK STATUS OF AVIONICS
      IF(IFAIL)EQ(1),GO TO 250
C     AVIONICS FAILED
      IF(IWRIT)EQ(2),WRITE ON 61,TIME,ID(SORT)
      FORMAT(S5,F3.2,S4,*AC 1 AVIONIC FAILURE, SORTIE *,I3,* REFILED*)
      FILE SORT IN TARC
C     AIRCRAFT RETURNS TO BASE, TEST AGAINST AREA DEFENSES
      LET R=RANDM
      LET SP=SVPB(1,IPA)
C     CHECK TO SEE IF AIRCRAFT HIT
      IF(R)LE(SP),GO TO 210
C     AIRCRAFT HIT
      LET CP=CPB(1)
C     CHECK TO SEE WHETHER AIRCRAFT KILLED OR DAMAGED
      LET R=RANDM
      IF(R)LE(CP),GO TO 220
C     AIRCRAFT KILLED, CAUSE REPLC AT TIME + 1/2 DAY
      IF(IWRIT)EQ(2),WRITE ON 61,TIME
      FORMAT(S5,F3.2,S4,*AC 1 KILLED ON RETURN*)
      LET KAC(1)=KAC(1)+1
      CREATE REPLC
      LET I(REPLC)=1
      CAUSE REPLC AT TIME + 0.5
C     SEE IF SORTIE CAN BE REASSIGNED
      CALL DSRCH
      DESTROY ARRIV
      RETURN
  210 CREATE REFRA
C     AIRCRAFT RETURNS TO BASE WITH AVIONIC FAILURE
      LET IKA(REFRA)=1
      CAUSE REFRA AT TIME + RET
      IF(IWRIT)EQ(2),WRITE ON 61,TIME
      FORMAT(S5,F3.2,S4,*AC 1 RETURNS WITH AVIONIC FAILURE*)
C     SEE IF SORTIE CAN BE REASSIGNED
      CALL DSRCH
      DESTROY ARRIV
      RETURN
```

```
C       AIRCRAFT DAMAGED, CAUSE REPR AT TIME + RETURN TIME
   220 CREATE REPR
       LET IK(REPR)=1
       CAUSE REPR AT TIME + RET
       IF(IWRIT)EQ(2),WRITE ON 51,TIME
       FORMAT(S5,F7.2,S4,*AC 1 RETURNS TO BASE DAMAGED*)
C       SEE IF SORTIE CAN BE REASSIGNED
       CALL DSFCH
       DESTROY ARRIV
       RETURN
C       AIRCRAFT ARRIVES FOR FIRST PASS AT TARGET
   250 LET N=1
   251 LET R=RANDM
C       TEST AGAINST LOCAL TARGET DEFENSES
       LET SV=SVTI(TYPE(SORT),INX)
       IF(R)GT(SV),GO TO 260
C       AIRCRAFT SURVIVES LOCAL DEFENSES ON THIS PASS
       LET PK=PKTI(TYPE(SORT),INX)
C       TEST TO SEE IF TARGET IS KILLED
       LET R=RANDM
       IF(R)LE(PK),GO TO 280
C       TARGET NOT KILLED, REATTACK?
       IF(IWRIT)EQ(2),WRITE ON 51,TIME
       FORMAT(S5,F7.2,S4,*AC 1 MAKES PASS, TARGET NOT KILLED*)
       LET N=N+1
C       CHECK NUMBER OF PASSES (ONLY TWO ALLOWED)
       IF(N)GE(3),GO TO 252
C       REATTACK TARGET
       GO TO 251
   252 FILE SORT IN TARC
C       TWO PASSES MADE AND TARGET NOT KILLED
       IF(IWRIT)EQ(2),WRITE ON 51,TIME,ID(SORT)
       FORMAT(S5,F7.2,S4,*2ND PASS BY AC 1, SORTIE *,I3,* REFILED*)
C       SEE IF SORTIE CAN BE REASSIGNED
       CALL DSFCH
       GO TO 281
   260 FILE SORT IN TARC
C       AIRCRAFT HIT
       LET LP=LVTI(TYPE(SORT))
C       CHECK TO SEE WHETHER AIRCRAFT KILLED OR DAMAGED
       LET R=RANDM
       IF(R)LE(LP),GO TO 270
C       AIRCRAFT KILLED, CAUSE REPLC AT TIME + 1/2 DAY
       IF(IWRIT)EQ(2),WRITE ON 51,TIME,ID(SORT)
       FORMAT(S5,F7.2,S4,*AC 1 KILLED AT TARGET, SORTIE *,I3,* REFILED*)
       LET NAC(1)=NAC(1)+1
       CREATE REPLC
       LET IK(REPLC)=1
       CAUSE REPLC AT TIME + 0.5
C       SEE IF SORTIE CAN BE REASSIGNED
       CALL DSFCH
       DESTROY ARRIV
       RETURN
C       AIRCRAFT DAMAGED, CAUSE REPR AT TIME + RETURN TIME
   270 CREATE REPR
       LET IK(REPR)=1
       CAUSE REPR AT TIME + RET
       IF(IWRIT)EQ(2),WRITE ON 61,TIME,ID(SORT)
       FORMAT(S5,F7.2,S4,*AC 1 DAMAGED AT TARGET, SORTIE *,I3,* REFILED*)
C       SEE IF SORTIE CAN BE REASSIGNED
       CALL DSFCH
       DESTROY ARRIV
       RETURN
C       TARGET KILLED (SORTIE REQUEST FULFILLED)
   280 LET NTKL(TYPE(SORT))=NTKL(TYPE(SORT))+1
       IF(IWRIT)EQ(2),WRITE ON 51,TIME,ID(SORT)
```

```
      FORMAT(S5,M3.2,S4,*AC 1 KILLS TARGET ON SORTIE *,I3)
      DESTROY SORT
C     TEST AGAINST AREA DEFENSES ON RETURN TO BASE
  281 LET R=RANDM
      LET SP=SVFB(1,INX)
C     CHECK TO SEE IF AIRCRAFT HIT
      IF(R)LE(SP),GO TO 285
C     AIRCRAFT HIT
      LET CP=CVFB(1)
C     CHECK TO SEE IF AIRCRAFT KILLED OR DAMAGED
      LET R=RANDM
      IF(R)LE(CP),GO TO 290
C     AIRCRAFT KILLED, CAUSE REPLC AT TIME + 1/2 DAY
      IF(IWRIT)EQ(2),WRITE ON 61,TIME
      FORMAT(S5,M3.2,S4,*AC 1 KILLED ON RETURN TO BASE*)
      LET KAC(1)=KAC(1)+1
      CREATE REPLC
      LET I(REPLC)=1
      CAUSE REPLC AT TIME + 0.5
      DESTROY ARRIV
      RETURN
C     AIRCRAFT RETURNS UNDAMAGED TO BASE, CAUSE REFUL AT TIME + RET
  285 CREATE REFUL
      LET IK(REFUL)=1
      CAUSE REFUL AT TIME + RET
      IF(IWRIT)EQ(2),WRITE ON 61,TIME
      FORMAT(S5,M3.2,S4,*AC 1 RETURNS TO BASE TO REFUEL*)
      DESTROY ARRIV
      RETURN
C     AIRCRAFT DAMAGED, CAUSE REPR AT TIME + RET
  290 CREATE REPR
      LET IK(REPR)=1
      CAUSE REPR AT TIME + RET
      IF(IWRIT)EQ(2),WRITE ON 61,TIME
      FORMAT(S5,M3.2,S4,*AC 1 DAMAGED ON RETURN TO BASE*)
      DESTROY ARRIV
      RETURN
      END
```

```
      ENDOGENOUS EVENT REFRA
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
C     THIS EVENT IS THE REPAIR TIME FOR AN AIRCRAFT WITH AN AVIONIC
C     FAILURE.  REPAIR TIMES ARE GENERATED FROM AN EXPONTIAL TIME TO
C     REPAIR MODEL.  ONCE THE AIRCRAFT HAS COMPLETED REPAIR, THEN EVENT
C     REFLC IS CAUSED AT TIME + REPAIR TIME + REFUEL TIME.
      LET WINC=IRA(REFRA)
      IF(WINC)[illegible](1),GO TO 10
      LET RMU=ALOG(MTPA2/SQRT(1.C[illegible]))
      LET RSIG=SQRT(AL[illegible](1.C[illegible]))
      LET U1=RANDM
      LET U2=RANDM
      LET RN[illegible]SQRT(-[illegible]*ALOG(U1))*COS(6.2831852*U2)
      LET TR=EXP([illegible]*RNORM + RMU)
      LET NAV[illegible]=NAV[illegible]+1
      LET TART[illegible]=TART[illegible]+TR
      CREATE REFLC
      LET I(REFLC)=2
      LET TR=TR+RFL2
      CAUSE REFLC AT TIME + TR
      IF(IWRIT)[illegible],WRITE ON 61,TIME,TR
      FORMAT(S[illegible],[illegible],[illegible],*AC 2 AVIONIC REPAIR, REPAIR+REFUEL=*,H3.0)
      DESTROY REFRA
      GO TO 20
   10 LET RMU=ALOG(MTPA1/SQRT(1.C[illegible]))
      LET RSI[illegible]SQRT(AL[illegible](1.C[illegible]))
      LET U1=RANDM
      LET U2=RANDM
      LET RN[illegible]SQRT(-[illegible].0*ALOG(U1))*COS(6.2831852*U2)
      LET TR=EXP(RSI[illegible]*RNORM + RMU)
      LET NAV1=NAV1+1
      LET TART1=TART1+TR
      CREATE REFLC
      LET I(REFLC)=1
      LET TR=TR+RFL1
      CAUSE REFLC AT TIME + TR
      IF(IWRIT)[illegible],WRITE ON 61,TIME,TR
      FORMAT(S[illegible],[illegible].2,[illegible],*AC 1 AVIONIC REPAIR, REPAIR+REFUEL=*,H3.0)
      DESTROY REFRA
   20 RETURN
      END
```

```
      ENDOGENOUS EVENT REPR
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
C     THIS EVENT IS THE REPAIR TIME FOR A BATTLE DAMAGED AIRCRAFT.
C     REPAIR TIMES ARE GENERATED FROM AN EXPONENTIAL TIME TO REPAIR
C     MODEL.  ONCE THE AIRCRAFT IS REPAIRED, THEN EVENT REPLC IS CAUSED
C     AT TIME + REPAIR TIME + REFUEL TIME.
      LET MINC=IM(REPR)
      IF(MINC)EQ(1),GO TO 10
      LET RMU=ALOG(MTR2 /SQRT(1.0961))
      LET RSIG=SQRT(ALOG(1.0961))
      LET U1=RANDM
      LET U2=RANDM
      LET RNORM=SQRT(-2.0*ALOG(U1))*COS(6.2831852*U2)
      LET TR=EXP(RSIG*RNORM + RMU)
      LET NCM2=NCM2+1
      LET TRT2=TRT2+TR
      CREATE REPLC
      LET I(REPLC)=2
      LET TR=TR+RFL2
      CAUSE REPLC AT TIME + TR
      IF(IWRITE)EQ(2),WRITE ON 61,TIME,TR
      FORMAT(S5,M7.2,S4,*AC 2 DAMAGE REPAIR, REPAIR+REFUEL=*,M3.8)
      DESTROY REPR
      GO TO 20
   10 LET RMU=ALOG(MTR1 /SQRT(1.0961))
      LET RSIG=SQRT(ALOG(1.0961))
      LET U1=RANDM
      LET U2=RANDM
      LET RNORM=SQRT(-2.0*ALOG(U1))*COS(6.2831852*U2)
      LET TR=EXP(RSIG*RNORM + RMU)
      LET NCM1=NCM1+1
      LET TRT1=TRT1+TR
      CREATE REPLC
      LET I(REPLC)=1
      LET TR=TR+RFL1
      CAUSE REPLC AT TIME + TR
      IF(IWRITE)EQ(2),WRITE ON 61,TIME,TR
      FORMAT(S5,M7.2,S4,*AC 1 DAMAGE REPAIR, REPAIR+REFUEL=*,M3.8)
      DESTROY REPR
   20 RETURN
      END
```

```
      ENDOGENOUS EVENT REFUL
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
C     THIS EVENT IS THE REFUELING OF UNDAMAGED AIRCRAFT WHICH HAVE
C     RETURNED FROM FLYING SORTIES.  IT CAUSES EVENT REPLC TO OCCUR
C     AT TIME + REFUELING TIME.
      LET KINC=IK(REFUL)
      IF(KINC)EQ(1),GO TO 10
      CREATE REPLC
      LET I(REPLC)=2
      CAUSE REPLC AT TIME + RFL2
      IF(IWRIT)EQ(2),WRITE ON 61,TIME,RFL2
      FORMAT(S5,M7.2,S4,*AC 2 REFUELS, TIME = *,M3.9)
      DESTROY REFUL
      GO TO 20
   10 CREATE REPLC
      LET I(REPLC)=1
      CAUSE REPLC AT TIME + RFL1
      IF(IWRIT)EQ(2),WRITE ON 61,TIME,RFL1
      FORMAT(S5,M7.2,S4,*AC 1 REFUELS, TIME = *,M3.8)
      DESTROY REFUL
   20 RETURN
      END
```

```
      ENDOGENOUS EVENT REPLC
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
C     THIS EVENT IS THE RETURN OF AN AIRCRAFT TO READY STATUS.  ONCE AN
C     AIRCRAFT IS RETURN, SUBROUTINE DSPCH IS CALLED TO SEE IF ANOTHER
C     MATCH CAN BE MADE FOR WAITING SORTIE REQUESTS.
      LET KIND=I(REPLC)
      LET AC(KIND)=AC(KIND)+1
      IF(IWRIT)EQ(1),WRITE ON 61,TIME,KIND,AC(KIND)
      FORMAT(S5,M5.2,S4,*AC *,I2,*RETURNED TO LINE, TOTAL NOW = *,I2)
      CALL DSPCH
      DESTROY REPLC
      RETURN
      END
```

```
      ENDOGENOUS EVENT TESTW
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
C     THIS EVENT OCCURS EVERY HOUR.  IT SIMULATES CHANGES IN THE WEATHER
C     BY MODELLING THE WEATHER STATES AS A MARKOV PROCESS.  THE CURRENT
C     WEATHER STATE IS INDICATED BY "WST".
      LET IPVWST=WST
      LET FCUM=0.0
      LET R=RANDM
C     THE NEW WEATHER STATE IS FOUND BY COMPARING A RANDOM NUMBER
C     FROM A 0-1 DISTRIBUTION AGAINST A CUMULATIVE PROBABILITY TERM
C     CALCULATED FROM THE ELEMENTS OF THE TRANSITION MATRIX.
      DO,FOR N=(1)(10)
      LET FCUM=FCUM+A(WST,N)
      IF(R.LE.FCUM),GO TO 10
      LOOP
   10 LET WST=N
      LET ITWST(N)=ITWST(N)+1
      IF(IWRITE.E.(1)),WRITE ON 61,TIME,IPVWST,WST
      FORMAT([illegible],*WEATHER CHANGES FROM *,I2,* TO *,I2)
      IF(IPVWST.[illegible]),GO TO 20
      CALL DSFCH
   20 DESTROY TESTW
      RETURN
      END
```

```
      ENDOGENOUS EVENT ENDSM
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
         WRITE ON 61,TIME
      FORMAT(S5,F3.2,S4,*END OF SIMULATION*//)
      STOP
      END
```

```
      ENDOCCENCES EVENT DAYRP
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
C     THIS EVENT IS SCHEDULED AT THE END OF EACH SIMULATED DAY.  THE
C     PURPOSE OF THIS EVENT IS TO PRINT OUT A DAILY SUMMARY OF THE
C     IMPORTANT STATISTICS ASSOCIATED WITH THE SIMULATION.
      DIMENSION TWST(10)
      IF(I WRITE[illegible](1),WRITE ON 61,TIME
      FORMAT(///// 10,*SUMMARY REPORT FOR DAY *,42.2.2)
      IF(IWRITE)[illegible](1),WRITE ON 61
      FORMAT([illegible],*TYPE 1*,S14,*TYPE 2*)
      LET [illegible]
      LET [illegible]
      IF(IWRITE)[illegible](1),WRITE ON 61,NOM1,NOM2
      FORMAT(S1[illegible],*AIRCRAFT DAMAGED TODAY*,S10,I3,S17,I3)
      IF(IWRITE)[illegible](1),WRITE ON 61,NOMT1,NOMT2
      FORMAT([illegible],*AIRCRAFT DAMAGED TOTAL*,S10,I3,S17,I3)
      LET NAVT1[illegible]NAV1
      LET [illegible]
      IF(IWRITE)[illegible](1),WRITE ON 61,NAV1,NAV2
      FORMAT([illegible],*AVIONIC FAILURES TODAY*,S10,I3,S17,I3)
      IF(IWRITE)[illegible](1),WRITE ON 61,NAVT1,NAVT2
      FORMAT(S1[illegible],*AVIONIC FAILURES TOTAL*,S10,I3,S17,I3)
      LET [illegible](1)
      LET [illegible](2)
      IF(IWRITE)[illegible](1),WRITE ON 61,KAC(1),KAC(2)
      FORMAT(S1[illegible],*AIRCRAFT KILLED TODAY*,S11,I3,S17,I3)
      IF(IWRITE)[illegible](1),WRITE ON 61,NAKT1,NAKT2
      FORMAT(S10,*AIRCRAFT KILLED TOTAL*,S11,I3,S17,I3)
      LET [illegible]
      LET [illegible]
      LET [illegible]
      LET ART2[illegible]
      IF(IWRITE)[illegible](1),WRITE ON 61,ART1,ART2
      FORMAT(S10,*[illegible] AVERAGE REPAIR TIME*,S7,H2.3,S15,H2.3)
      LET [illegible]
      LET [illegible]
      LET [illegible]
      LET [illegible]
      IF(IWRITE)[illegible](1),WRITE ON 61,AART1,AART2
      FORMAT([illegible],*[illegible] AVIONIC REPAIR TIME*,S3,H2.3,S15,H2.3)
      IF(IWRITE)[illegible](1),WRITE ON 61,FLITE
      FORMAT(S1[illegible],*[illegible] SORTIES FLOWN TODAY =*,I8)
      IF(IWRITE)[illegible](1),WRITE ON 61,AC(1)
      FORMAT([illegible],*TYPE 1 AIRCRAFT AVAILABLE AT END OF DAY=*,I5)
      IF(IWRITE)[illegible](1),WRITE ON 61,AC(2)
      FORMAT(S10,*TYPE [illegible] AIRCRAFT AVAILABLE AT END OF DAY=*,I5)
      IF(IWRITE)[illegible](1),WRITE ON 61
      FORMAT(//[illegible],*TYPE    1       2       3       -       5       6*)
      LET [illegible]=NTKL(1)+NTKL(2)+NTKL(3)+NTKL(4)+NTKL(5)+NTKL(6)
      IF(IWRITE)[illegible](1),WRITE ON 61,NTKL(1),NTKL(2),NTKL(3),NTKL(4),NTKL(5)
     1,NTKL(6),NT[illegible]
      FORMAT(S1[illegible],*TARGETS DESTROYED TODAY*,S12,I3,S4,I3,S4,I3,S4,I3,S4,I
     13,S4,I3,S4,I3)
      [illegible]
      LET TTKL(K)=TTKL(K)+NTKL(K)
      LET NTKL(K)=[illegible]
      L[illegible]
      IF(IWRITE)[illegible](1),WRITE ON 61,TTKL(1),TTKL(2),TTKL(3),TTKL(4),TTKL(5)
     1,TTKL(6)
      FORMAT(S10,*TARGETS DESTROYED TOTAL*,S12,I[illegible],S4,I3,S4,I3,S4,I3,S4,I
```

```
1?,S4,I3)
 LET SUPT=TTKL(1)+TTKL(2)+TTKL(3)+TTKL(4)+TTKL(5)+TTKL(6)
 LET SUMA=NAKT1+NAKT2
 LET EXRT=999.0
 IF(SUMA)GT(0.0), LET EXRT=[illegible]T/SUMA
 IF(IWRIT)EQ(1),WRITE ON 61,EXRT
 FORMAT(S10,*EXCHANGE RATIO (TARGETS/AIRCRAFT) =*,D7.4//)
 IF(IWRIT)EQ(1),WRITE ON 61
 FORMAT(S10,*WEATHER STATE        PERCENT TODAY        CUM PERCENT*)
 LET TOTHR=0.0
 DO,FOR K=(1)(1)[illegible]
 LET TWST(K)=ITWST(K)
 LET [illegible]=[illegible]+TWST(K)
 LET TOTHR=TOTHR+TWST(K)
 LOOP
 DO,FOR K=(1)(1)[illegible]
 LET WSTPC=TWST(K)/24.0
 LET TWSTPC=CTWST(K)/TOTHR
 IF(IWRIT)EQ(1),WRITE ON 61,K,WSTPC,TWSTPC
 FORMAT([illegible],D1.4,S13,D1.4)
 LET ITWST(K)=0
 LOOP
C      THIS OUTPUT IS WRITTEN ON PUNCHED CARDS
 WRITE ON 5,KAC(1),KAC(2),NOM1,NOM2,NAV1,NAV2,FLITE,AC(1),AC(2),
1[illegible],EXRT
 FORMAT([illegible],I5,I5,I5,D7.4)
 IF(IWRIT)EQ(1),WRITE ON 61,TIME,NOMT1,NOMT2,NAVT1,NAVT2,NAKT1,
1NAKT2,[illegible]T1,[illegible]T2,AAWT1,AAWT2,FLITE,AC(1),AC(2),SUPT
 FORMAT([illegible],H4.3,H4.3,H4.3,H4.3,I5,I5,I5,D8.1)
C      REZERO THE DAILY COUNTER VARIABLES
 LET FLITE=0
 LET KAC(1)=0
 LET KAC(2)=0
 LET NOM1=0
 LET NOM2=0
 LET NAV1=0
 LET NAV2=0
 DESTROY DAYWP
 RETURN
 END
```

```
      SUBROUTINE DSPCH
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
C     THIS SUBROUTINE IS CALLED IF  1 AN AIRCRAFT BECOMES AVAILABLE
C                                   2 A SORTIE IS CANCELLED
C                                   3 A NEW SORTIE REQUEST IS RECEIVED
C                                   4 WEATHER CHANGES FROM STATE 1
C     THE SUBROUTINE CHECKS AVAILABLE AIRCRAFT AND THE LIST OF SORTIES
C     FILED IN A QUEUE NAMED TASC (RANKED BY EXPIRATION TIME) TO SEE IF
C     AN AIRCRAFT CAN BE MATCHED UP WITH A SORTIE REQUEST.  THE LOGIC
C     FIRST TRIES TO MATCH A 1ST CHOICE AIRCRAFT WITH A SORTIE.  IF THIS
C     IS NOT POSSIBLE, THEN IT CHECKS THE 2ND CHOICE AIRCRAFT FOR THE
C     SORTIE.  IF NO MATCH CAN BE MADE , THE SORTIE IS TEMPORARILY FILED
C     IN TPFL AND THE NEXT HIGHEST PRIORITY SORTIE IS CHECKED.  AT THE
C     END OF THE SUBROUTINE ALL SORTIES FILED IN TPFL ARE READ BACK INTO
C     THE QUEUE TASC SO THAT THEY CAN BE RECONSIDERED IN THE FUTURE.
C     IF A MATCH CAN BE MADE THEN EVENT FEBA IS CAUSED AT TIME + REAC.
      IF(WSTI)EQ(1),GO TO 60
      IF TASC IS EMPTY, GO TO 50
      LET ITOT=AC(1)+AC(2)
      IF(ITOT)EQ(0),GO TO 50
      LET DELTM=0.0
   10 IF TASC IS EMPTY, GO TO 40
      LET ITOT=AC(1)+AC(2)
      IF(ITOT)EQ(0),GO TO 40
      REMOVE FIRST SORT FROM TASC
      IF(SORTE(SORT))GE(TIME),GO TO 15
      DESTROY SORT
      GO TO 10
   15 LET IA=WRQ1(SORT)/(10**(WST-1))
      LET IB=WRQ1(SORT)/(10**WST)
      LET I1=IA-(IB*10)
C     CHECK FIRST CHOICE AIRCRAFT FOR THIS SORTIE
      IF(AC(I1))GT(0),GO TO 30
C     FIRST CHOICE AIRCRAFT NOT AVAILABLE
      LET IA=WRQ2(SORT)/(10**(WST-1))
      LET IB=WRQ2(SORT)/(10**WST)
      LET I2=IA-(IB*10)
C     CHECK THE SECOND CHOICE AIRCRAFT FOR THIS SORTIE
      IF(I2)NE(0),GO TO 20
C     NO AIRCRAFT CAN BE ASSIGNED
      FILE SORT IN TPFL
      GO TO 10
   20 LET AC(I2)=AC(I2)-1
C     ASSIGN SECOND CHOICE AIRCRAFT TO THIS SORTIE
      IF(IWRIT)EQ(2),WRITE ON 51,TIME,I2,ID(SORT)
      FORMAT(S4,M7.2,S4,*AC *,I2,* ASSIGNED AS 2ND CHOICE, SORTIE *,I3)
      CREATE FEBA
      STORE SORT IN SRT(FEBA)
      LET ITP(FEBA)=I2
      LET WHI(FEBA)=WST
      CAUSE FEBA AT TIME+REAC+DELTM
      LET DELTM=DELTM + 0.00208333
C     RETURN TO SEE IF MORE SORTIES CAN BE ASSIGNED
      GO TO 10
   30 LET AC(I1)=AC(I1)-1
C     ASSIGN FIRST CHOICE AIRCRAFT TO THIS SORTIE
      IF(IWRIT)EQ(2),WRITE ON 51,TIME,I1,ID(SORT)
      FORMAT(S4,M7.2,S4,*AC *,I2,* ASSIGNED AS 1ST CHOICE, SORTIE *,I3)
      CREATE FEBA
      STORE SORT IN SRT(FEBA)
```

```
      LET ITF(FEBA)=I1
      LET NN(FEBA)=NST
      CAUSE FEBA AT TIME+REAC+DELTM
      LET DELTM=DELTM + 0.00208333
C     RETURN TO SEE IF MORE SORTIES CAN BE ASSIGNED
      GO TO 10
C     CHECK TO SEE IF THERE ARE ANY SORTIES TO BE READ FROM TPFL TO TASC
   40 IF TPFL IS EMPTY, GO TO 50
      REMOVE FIRST SORT FROM TPFL
      FILE SORT IN TASC
      GO TO 40
   50 RETURN
      END
```

```
      SUBROUTINE AVION(IFAIL,IAC)
C     (COMPILED AND EXECUTED ON THE CDC 6600 COMPUTER LOCATED AT
C     WRIGHT-PATTERSON AIR FORCE BASE, OHIO.   THIS PROGRAM IS COMPILED
C     UNDER THE SIMSCRIPT 1.5 LANGUAGE COMPILER.)
C     THIS SUBROUTINE SIMULATES AN EXPONENTIAL SORTIE TO FAILURE MODEL.
C     SORTIES ARE COUNTED UNTIL THE PREDICTED AVIONIC FAILURE OCCURS.
C     ONCE THIS FAILURE OCCURS, THEN A NEW EXPONENTIAL PREDICTION IS
C     COMPLETED.   SEPARATE COUNTS ARE KEPT FOR EACH AIRCRAFT TYPE.
C     FOR EACH SORTIE THE SUBROUTINE COMPUTES A NEW IFAIL VALUE WHERE
C             IFAIL = 1 IF AVIONICS ARE OPERATING
C                     0 IF AVIONICS HAVE FAILED
      IF(IAC)EQ(2),GO TO 20
      IF(NST1)GT(0),GO TO 10
      LET IFAIL=0
      LET R=RANDOM
      LET NST1=0.5-MTBF1*ALOG(1.0-R)
C     0.5 IS ADDED TO NST1 TO ACCOUNT FOR TRUNCATION ERROR
      GO TO 40
   10 LET NST1=NST1-1
      LET IFAIL=1
      GO TO 40
   20 IF(NST2)GT(0),GO TO 30
      LET IFAIL=0
      LET R=RANDOM
      LET NST2=0.5-MTBF2*ALOG(1.0-R)
C     0.5 IS ADDED TO NST2 TO ACCOUNT FOR TRUNCATION ERROR
      GO TO 40
   30 LET NST2=NST2-1
      LET IFAIL=1
   40 RETURN
      END
```

```
CORE MAP  12.54.36.  NORMAL              CONTROL                                                          000100    027365    000000    000000
          ---TIME---LOAD MODE --L1--L2-----TYPE---------------USER---*----CALL-------------FWA LOAD--LWA LOAD--BLNK COMN--LENGTH--
          FWA LOADER  050767  FWA TABLES  042623
          -PROGRAM----ADDRESS-                     --LABELED---COMMON--
          **DF1        000100
          **DF2        000113
          **DF3        000130
          **DF4        000144
          **DF5        000154
          **DF6        000351
          **DF7        000552
          **EVLST      000601
          *THW         000751
          *LIST        002344
          *RQST        002676
          *FFBS        003115
          *ARRIV       003377
          *P PRA       005536
          *WEPW        006013
          *RCFUL       006262
          *RPPLC       006376
          *TESTW       006446
          *ENDSM       006555
          *JAYMP       006605
          DSPCH        007761
          AVION        010330
          FMF          010427
          IRAIEX       010566
          SINCOS       010537
          SQRT         010636
          SYSTEM       010701                  SCOPE2      010701
          ALNLOG       012065
          WAHF         012074
          WRAIEX       012106
          ARAPEX       012147
          GETBA        012226
          SIGT         012243
          **INIT       013716
          **ERR        022267
          ERRLP        023301
          ***DAT       023211
          **CNVM1      023240
          **CARG1      023423
          **T1         023437
          **OPEN       023442
          **INF1       023600
          **LINK1      024747
          **EM1        024770
          **OUTP1      025003
          **CNMM1      025673
          WRANG        026161
          **RAINS      026233
          **TMR        026277
          CRAOS        026507
          FILEMV       027004
          -----UNSATISFIED EXTERNALS-----                     REFERENCES
```

```
INITIALIZATION CARDS
1X         5     60    2-1           60    60    61    55
  1   4 0  Z                                                   QUEUES
  5     0 R                                        2           SVFBR
  6     0 R                                       10           SVFBC
  7     2 R     2   5  10    6      R 4           10(01.3)   SVFB
1.000 .990 .986 .988 .940 .960 .980 .934 .920 .960
1.000 .990 .996 .998 .992 .994 .996 .992 .994 .996
  8     0 R                                        2           DVFBC
  9     1 R     2    8                             2(01.3)     DVFB
.500 .500
 10     0 R                                        2           NFACR
 11     0 R                                        6           NFACC
 12     2 R     2  10   6  11      R 4             6(I2)       NFAC
0 0 0 1 0 1
0 0 0 1 0 1
 13     0 R                                        6           FACC
 14     1 R     6  13                              6(01.3)     FAC
1.00 1.00 0.99 0.97 0.95 0.95
 15     0 R                                        2           KACC
 16     1  Z    2  15                                          KAC
 17     0 R                                        6           SVT2R
 18     0 R                                       10           SVT2C
 19     2 R     6  17  10  18      R 4            10(01.3)    SVT2
.500 .260 .273 .267 .667 .500 .333 .333 .840 .823
.000 .520 .510 .500 .760 .640 .540 .465 .832 .793
.000 .300 .300 .292 .833 .817 .460 .370 .967 .950
.000 .554 .554 .550 .590 .873 .370 .374 .970 .960
.000 .297 .297 .240 .620 .513 .737 .357 .363 .947
.000 .562 .592 .548 .860 .375 .368 .372 .968 .958
 20     0 R                                        6           SVT1R
 21     0 R                                       10           SVT1C
 22     2 R     6  20  10  21      R 4            10(01.3)    SVT1
.000 .290 .273 .267 .667 .500 .333 .400 .840 .820
.000 .520 .510 .500 .760 .640 .540 .540 .832 .790
.000 .290 .283 .277 .767 .500 .433 .450 .940 .460
.000 .520 .514 .504 .640 .720 .500 .436 .882 .850
.000 .257 .260 .274 .765 .547 .433 .447 .937 .757
.000 .522 .512 .500 .520 .713 .390 .334 .880 .948
 23     0 R                                        6           DVTC
 24     1 R     6  23                              6(01.3)     DVT
.700 .600 .700 .500 .700 .500
 25     0 R                                        6           PKT2R
 26     0 R                                       10           PKT2C
 27     2 R     6  25  10  26      R 4            10(01.3)    PKT2
0.00 0.91 0.83 0.75 0.90 0.92 0.99 0.95 0.93 0.91
0.00 0.50 0.42 0.74 0.65 0.91 0.34 0.34 0.92 0.90
0.00 0.50 0.47 0.41 0.75 0.74 0.70 0.79 0.78 0.76
0.00 0.49 0.46 0.40 0.75 0.74 0.59 0.79 0.78 0.75
0.00 0.40 0.77 0.71 0.60 0.73 0.75 0.32 0.52 0.50
0.00 0.78 0.75 0.69 0.50 0.79 0.75 0.32 0.31 0.30
 28     0 R                                        6           PKT1R
 29     0 R                                       10           PKT1C
 30     2 R     6  28  10  29      R 4            10(01.3)    PKT1
0.00 0.81 0.83 0.75 0.90 0.92 0.99 0.95 0.93 0.91
0.00 0.50 0.42 0.74 0.65 0.91 0.38 0.94 0.92 0.90
0.00 0.44 0.42 0.39 0.45 0.44 0.42 0.50 0.49 0.47
0.00 0.43 0.41 0.39 0.45 0.43 0.41 0.50 0.48 0.46
0.00 0.74 0.72 0.69 0.60 0.57 0.54 0.52 0.59 0.56
0.00 0.72 0.70 0.67 0.60 0.56 0.53 0.52 0.58 0.55
 31     0 R                                        6           NTKLC
 32     1  Z    6  31                                          NTKL
 33     0 R                                        2           ACC
```

```
34     1 F    2  33                              2(I5)          AC
   6    24
35     0 R                                       10             AROW
36     0 R                                       10             ACOL
37     2 R    10  35  10  36      R N            10(D1.3)       A
1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 1.00 0.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 1.00 0.00
0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 1.00
38     0 R                                       0.01388888     TARG
39     0 R                                       0.02083333     RET
40     0 R                                        1             STID
41     0 R                                        4             WST
42     0 R                                       0.02777777     REAC
43     0 R                                        6             NST1
44     0 R                                        4             NST2
45     0 R                                        6.2869515     MTBF1
46     0 R                                        3.3867591     MTBF2
47     0 R                                       0.0429237      MTBA1
48     0 R                                       0.1397416      MTBA2
49     0 R                                       0.5            MTB1
50     0 R                                       0.75           MTB2
51     0 R                                        0.05          RFL1
52     0 R                                        0.35          RFL2
53     0 R                                        2151.0        NHRS
54     0 R                                        1             IWRIT
55  65 0  Z                                                     IDS
65     0 R                                        6             ITKLC
70     1  Z     6  69                                           ITKL
71     0 R                                        10            ITWSC
72     1  Z    10  71                                           ITWST
73     0 R                                        10            CTWSC
74     1  Z    10  73                                           CTWST
75     0 R                                        4             NUMB1
76     0 R                                        14            NUMB2
77     0 R                                        12            NUMB3
78     0 R                                        5             NUMB4
79     0 R                                        536787        ISEED
80     0  Z                                                     FLITE
```

CLOSE AIR SUPPORT SIMULATION
DEVELOPED BY F.K. LLOYD
AFIT/ENS (GSA-73) 23 JAN 73

SVFB IAC=ROWS IMX=COLUMNS

1.0	0.950	0.946	0.949	0.940	0.950	0.980	0.984	0.920	0.940
1.0	0.996	0.940	0.936	0.992	0.994	0.996	0.992	0.994	0.996

DVFB IAC=ROWS
0.500
0.500

NFAC IAC=ROWS TYPE(SORT)=COLUMNS

0	0	0	1	0	1
0	0	0	1	0	1

FAC TYPE(SORT)=ROWS
1.0
1.0
0.940
0.970
0.950
0.950

SVT2 TYPE(SORT)=ROWS IMX=COLUMNS

0.0	0.280	0.273	0.257	0.667	0.530	0.333	0.950	0.840	0.820
0.0	0.520	0.513	0.533	0.783	0.640	0.540	0.846	0.832	0.798
0.0	0.330	0.323	0.233	0.833	0.817	0.800	0.973	0.967	0.950
0.0	0.564	0.554	0.550	0.890	0.878	0.870	0.976	0.978	0.966
0.0	0.297	0.297	0.230	0.830	0.817	0.797	0.967	0.963	0.947
0.0	0.562	0.552	0.545	0.886	0.876	0.868	0.972	0.968	0.958

SVT1 TYPE(SORT)=ROWS IMX=COLUMNS

0.0	0.280	0.273	0.257	0.667	0.500	0.333	0.850	0.840	0.820
0.0	0.520	0.513	0.500	0.783	0.640	0.540	0.846	0.832	0.790
0.0	0.290	0.283	0.277	0.767	0.630	0.433	0.950	0.940	0.800
0.0	0.524	0.514	0.504	[illegible]	0.723	0.633	0.906	0.882	0.850
0.0	0.287	0.283	0.273	0.763	0.517	0.430	0.947	0.937	0.767
0.0	0.522	0.512	0.502	0.834	0.718	0.598	0.904	0.950	0.848

DVT TYPE(SORT)=ROWS
0.700
0.500
0.700
0.500
0.700
0.500

PKT2 TYPE(SORT)=ROWS IMX=COLUMNS

0.0	0.910	0.830	0.750	0.900	0.970	0.890	0.950	0.930	0.910
0.0	0.800	0.820	0.740	0.890	0.910	0.880	0.960	0.920	0.900
0.0	0.500	0.470	0.410	0.750	0.740	0.760	0.790	0.780	0.760
0.0	0.490	0.460	0.403	0.750	0.740	0.690	0.790	0.780	0.750
0.0	0.900	0.770	0.710	0.800	0.730	0.750	0.820	0.820	0.800
0.0	0.780	0.750	0.640	0.800	0.730	0.750	0.820	0.810	0.800

PKT1 TYPE(SORT)=ROWS IMX=COLUMNS

0.0	0.910	0.830	0.740	0.900	0.920	0.890	0.950	0.930	0.910
0.0	0.800	0.820	0.740	0.890	0.910	0.880	0.940	0.920	0.900
0.0	0.440	0.420	0.340	0.450	0.440	0.420	0.500	0.490	0.470
0.0	0.430	0.410	0.330	0.450	0.430	0.410	0.560	0.490	0.460
0.0	0.740	0.720	0.640	0.600	0.570	0.540	0.620	0.590	0.560
0.0	0.72[illegible]	[illegible]	[illegible]	0.6[illegible]	[illegible]	0.570	0.620	0.540	0.550

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```
AC   IAC=ROWS
  0
  24

A  NST=ROWS   N=COLUMNS
1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
0.0    1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
0.0    0.0    1.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
0.0    0.0    0.0    1.0    0.0    0.0    0.0    0.0    0.0    0.0
0.0    0.0    0.0    0.0    1.0    0.0    0.0    0.0    0.0    0.0
0.0    0.0    0.0    0.0    0.0    1.0    0.0    0.0    0.0    0.0
0.0    0      0.0    0.0    0.0    0.0    1.0    0.0    0.0    0.0
0.0    0      0.0    0.0    0.0    0.0    0.0    1.0    0.0    0.0
0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    1.0    0.0
0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0    1.0
TARG= 19 MINS
RET = 29 MINS
REAC= 39 MINS
NST =  8
MTBF1=  6.2[illegible] SORTIES
MTBF2=  3.586759[illegible] SORTIES
MTBA1=  1.59[illegible] HRS
MTBA2=  2.63379[illegible] HRS
MTTE1 = 12.0          HRS
MTTE2 = 18.0          HRS
RFL1 = 72 MINS
RFL2 = 72 MINS
NHRS =      [illegible]101. HRS
NUMB1=  4 SORTIES
NUMB2= 14 SORTIES
NUMB3= 13 SORTIES
NUMB4=  5 SORTIES
```

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APPENDIX C

DAILY COSTS OF ORDNANCE EXPENDED IN HYPOTHETICAL EXAMPLE

Appendix C

Daily Costs of Ordnance Expended in Hypothetical Example

This Appendix describes the method by which the approximate ordnance costs listed in Table 6.3, Chapter VI, were computed.

The computations were based on the following factors:

(1) The weighted average probabilities of being hit by area and target defenses and weighted average probabilities of killing the target on one pass;

(2) The weights used in averaging the probabilities correspond to the weather state frequencies-of-occurrence for winter and summer weather conditions;

(3) A 0/24 aircraft mix, 24/0 mix, and a mix where each sortie is flown by the preferred aircraft as identified by the aircraft preference codes described in Chapter IV;

(4) 36 sorties flown per day, uniformally distributed among the 6 target types;

(5) A Type 1 ordnance load of,

(a) Eight 500/750 lb Bombs

(b) Four Cluster Bomb Units

(c) Four Napalm Bombs

At an approximate cost of $19,000;

(6) A Type 2 ordnance load of,

(a) Two Standoff Weapons @ $20,000

(b) Eight 500/750 lb Bombs

(c) Four Cluster Bomb Units

At an approximate cost of $58,000;

Appendix C (Continued)

(7) Costs were based on approximate dollar costs of representative weapons;

(8) Type 1 aircraft expend half their ordnance on each pass;

(9) Type 2 aircraft expend one standoff weapon per pass or half their standard ordnance per pass;

(10) Aircraft return to base with their remaining ordnance if target is killed on the first pass;

(11) Aircraft jettison all ordnance if hit by enemy defenses;

(12) Type 2 either uses standoff weapons or standard ordnance on a sortie -- never both;

(13) The probability of a FAC being available was not considered;

(14) Avionics failures prior to weapons delivery were not considered;

(15) Costs of cannon ammunition considered to be the same for both aircraft and therefore, not differential.

Following are the average ordnance costs per day for the different mixes, aircraft types, and weather conditions:

"Preferred Aircraft" Mix

	Winter	Summer	
Type 1	$265,430	$252,415	($328,140)
Type 2	$437,240	$364,540	($473,902)

"0/24" Mix

	Winter	Summer	
Type 2	$970,583	$731,556	($951,023)

"24/0" Mix

	Winter	Summer	
Type 1	$474,680	$428,735	($557,356)

The numbers in parentheses are based on a sortie rate of 1.3 x 36 = 46.8 sorties flown per day. Simulation results have shown that this is a more

Appendix C (Continued)

realistic rate for the summer weather conditions. The numbers in parentheses were used in Chapter VI.

The method of computing these costs will now be illustrated by a few examples. The weighted averages were computed by multiplying the probabilities from the input data by the expected frequency-of-occurrence of the corresponding weather states and averaging the results. An example follows:

Weighted Averages of Probabilities of Not
Being Hit by Target Defenses
(Single Pass--0/24 Mix)

Weather State	Weights Winter	Weights Summer	$P_{\bar{h}}$*	$P_{\bar{h}}$ x Wts. Winter	$P_{\bar{h}}$ x Wts. Summer
2	3.9	2.4	.404	1.575	.969
3	1.9	1.0	.395	.751	.395
4	11.4	2.9	.387	4.413	1.123
5	4.4	4.7	.776	3.414	3.646
6	1.6	2.4	.629	1.007	1.510
7	8.8	3.9	.489	4.303	1.907
8	15.7	38.4	.901	14.138	34.579
9	4.7	21.9	.885	4.160	19.382
10	21.8	19.2	.813	17.713	15.600
Totals	74.2	96.8		51.474	79.113

$$\frac{51.474}{74.2} = .694 \qquad \frac{79.113}{96.8} = .817$$

* $P_{\bar{h}}$ is the average probability for all 6 sortie types.

Therefore, .694 is the average probability that a Type 1 aircraft will not be hit by target defenses on a single pass under winter weather conditions. .817 is the average probability that a Type 1 aircraft will not be hit by target defenses on a single pass under summer weather conditions.

The following table shows all the weighted averages used in the analysis:

Appendix C (Continued)

Probability of Not Being Hit
by Target Defenses

	"Preferred A/C" Type 1	Type 2	0/24	24/0
Winter	.667	.931	.764	.694
Summer	.778	.951	.870	.817

Probability of Not Being Hit
by Area Defenses

	Type 1	Type 2
Winter	.947	.995
Summer	.926	.994

Probability of Killing Target
on Single Pass

	"Preferred A/C" Type 1	Type 2	0/24	24/0
Winter	.846	.778	.818	.645
Summer	.913	.791	.824	.664

The next step in the analysis was to calculate the expected numbers of aircraft that would complete certain events and survive certain enemy defenses. This was done using the average probabilities and the average number of sorties flown per day. For example, for 36 sorties flown per day, each flown by the preferred aircraft, 56 percent (20) would be flown by Type 1 aircraft and 44 percent (16) would be flown by Type 2. Then

For Winter -- Type 2 Aircraft

(1) $.995 \times 16 = 15.92$ aircraft survive area defenses on the way to the target.*

(2) $.931 \times 15.92 = 14.82$ aircraft survive the target defenses on the first pass.

Appendix C (Continued)

(3)	.778 x 14.82 =	11.53	aircraft kill the target on the first pass.
(4)	.995 x 11.53 =	11.47	of these survive area defenses on the way out.
(5)	.931 x 3.29 =	3.06	aircraft survive the target defenses on the second pass.
(6)		3.06	aircraft expend ordnance on the second pass.
(7)	.995 x 3.06 =	3.05	of the aircraft making a second pass survive the area defenses on the way out.

* Survive, in this case, refers to not being hit by ground fire.

These numbers were then used to compute the costs associated with each event. To continue the example,

(1)	.08 x $58,000 =	$ 4,640 =	cost of ordnance, standoff and standard, lost to area defenses on way in.
(2)	1.10 x $58,000 =	63,800 =	cost of standoff and standard ordnance lost to target defenses on first pass.
(3)	14.82 x $20,000 =	296,400 =	cost of standoff ordnance expended on first pass.
(4)	.06 x $38,000 =	2,280 =	cost of ordnance lost to area defenses on way out. (Aircraft which kill target on first pass)
(5)	.23 x $38,000 =	8,740 =	cost of ordnance lost to target defenses on second pass.
(6)	3.06 x $20,000 =	61,200 =	cost of standoff ordnance expended on second pass.
(7)	.01 x $18,000 =	180 =	cost of standard ordnance lost to area defenses on way out.
		$437,240	Total ordnance cost per day

Similar calculations were made for the other cases taking into account situations where the Type 2 aircraft expend standard ordnance only. These per day costs were then converted to costs per target killed by using the average number of targets killed per day under each weather condition.

APPENDIX D

EXAMPLE OF WEATHER PERSISTENCE DATA

CRITERIA H   CUMULATIVE % PROBABILITY OF CONTINUANCE OF CONDITIONS BY MONTH-START HOUR

STATION 14049   MONTH 04   PAGE 1

HOUR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
00	% CRI	15.2	12.8	10.8	8.3	5.5	4.1	3.0	2.6	2.2	2.2	2.0	1.8	1.7	1.5	1.1	.7	.6	.6	.6	.6
	VAL	541	541	541	541	541	541	541	541	541	541	541	541	541	541	541	541	541	540	539	539
01	% CRI	16.3	13.7	10.9	7.9	5.5	4.4	3.7	3.1	3.0	2.6	2.4	2.0	1.8	1.5	1.1	.9	.6	.6	.6	.6
	VAL	541	541	541	541	541	541	541	541	541	541	541	541	541	541	541	541	540	539	539	539
02	% CRI	17.0	13.7	10.0	6.5	5.0	4.3	3.5	3.3	3.0	2.8	2.2	2.0	1.7	1.3	1.1	.7	.6	.6	.4	.4
	VAL	541	541	541	541	541	541	541	541	541	541	541	541	541	541	541	540	539	539	539	539
03	% CRI	16.7	13.1	8.9	6.7	5.2	4.4	4.3	3.7	3.5	2.8	2.2	1.7	1.3	1.1	.7	.6	.6	.4	.4	.2
	VAL	541	541	541	541	541	541	541	541	541	541	541	541	541	541	540	539	539	539	539	539
04	% CRI	17.0	11.6	8.7	6.7	5.9	5.7	5.2	4.8	3.7	3.0	2.2	1.7	1.3	.9	.7	.7	.6	.6	.4	.4
	VAL	541	541	541	541	541	541	541	541	541	541	541	541	541	540	539	539	539	539	539	539
05	% CRI	15.7	11.8	8.9	7.8	7.6	6.8	6.3	5.0	4.1	3.0	2.2	1.7	1.1	.9	.7	.6	.6	.4	.4	.4
	VAL	541	541	541	541	541	541	541	541	541	541	541	541	540	539	539	539	539	539	539	539
06	% CRI	17.4	12.3	10.3	9.9	9.0	8.1	6.6	5.3	4.0	2.9	2.4	1.3	1.1	.9	.7	.7	.6	.6	.6	.2
	VAL	540	540	540	540	540	540	540	540	540	540	540	540	539	539	539	539	539	539	539	539
07	% CRI	17.9	14.3	13.0	11.7	10.3	8.4	6.8	5.3	4.0	3.5	2.2	1.7	1.1	.7	.7	.6	.6	.6	.2	.2
	VAL	540	540	540	540	540	540	540	540	540	540	540	539	539	539	539	539	539	539	539	539
08	% CRI	22.9	18.3	16.1	14.5	12.1	9.5	7.7	5.7	4.6	3.0	2.2	1.3	.9	.9	.7	.7	.7	.4	.4	.2
	VAL	540	540	540	540	540	540	540	540	540	540	539	539	539	539	539	539	539	539	539	539
09	% CRI	26.9	22.0	20.1	16.5	12.8	9.9	7.3	5.5	3.3	2.6	1.5	1.1	.9	.7	.7	.7	.4	.4	.2	.2
	VAL	540	540	540	540	540	540	540	540	540	539	539	539	539	539	539	539	539	539	539	539
10	% CRI	31.0	27.1	22.0	17.4	13.0	10.1	7.5	4.6	3.7	2.2	1.7	1.3	1.1	.9	.7	.4	.4	.2	.2	.2
	VAL	540	540	540	540	540	540	540	540	539	539	539	539	539	539	539	539	539	539	539	539
11	% CRI	30.3	28.9	21.8	16.5	12.5	8.8	5.2	3.9	2.6	1.7	1.3	1.1	.9	.7	.6	.4	.2	.2	.2	
	VAL	540	540	540	540	540	540	540	39	539	539	539	539	539	539	539	539	539	539	539	539

CRITERIA H — CUMULATIVE % PROBABILITY OF CONTINUANCE OF CONDITIONS BY MONTH-START HOUR

STATION 34049 — MONTH 04 — PAGE 2

HOUR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
12	% CHI	35.9	20.2	18.9	13.9	9.7	5.7	4.1	2.4	1.7	1.3	1.1	.9	.7	.4	.4	.2	.2	.2		
	VAL	540	540	540	540	540	540	539	539	539	539	539	539	539	539	539	539	539	539	539	539
13	% CHI	33.5	23.8	17.9	12.5	7.6	5.0	3.2	2.4	2.0	1.9	1.5	1.1	.7	.7	.6	.6	.4	.2	.2	.2
	VAL	540	540	540	540	540	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539
14	% CHI	30.2	21.6	14.8	9.3	5.9	3.5	2.6	2.0	1.9	1.5	1.1	.7	.7	.6	.6	.4	.2	.2	.2	.2
	VAL	540	540	540	540	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539
15	% CHI	28.8	19.0	11.5	7.6	4.8	3.7	2.8	2.6	2.0	1.5	1.1	1.1	.9	.9	.7	.6	.4	.4	.4	.4
	VAL	540	540	540	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539
16	% CHI	24.2	14.8	9.1	5.8	4.3	3.2	3.0	2.4	1.9	1.3	1.3	.9	.9	.7	.6	.4	.4	.4	.4	.2
	VAL	540	540	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539
17	% CHI	15.9	11.7	7.2	5.6	4.3	3.9	3.2	2.4	1.7	1.7	1.1	.9	.7	.6	.4	.4	.4	.4	.2	.2
	VAL	540	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539
18	% CHI	16.7	10.2	6.9	4.8	4.3	3.5	2.8	2.0	2.0	1.5	1.1	.9	.7	.6	.6	.6	.6	.4	.4	.4
	VAL	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539
19	% CHI	15.8	10.9	6.7	5.6	4.1	3.2	2.4	2.4	1.9	1.3	1.1	.9	.7	.7	.7	.7	.6	.6	.6	.2
	VAL	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539
20	% CHI	15.0	9.1	7.1	5.4	4.3	3.0	3.0	2.4	1.5	1.3	1.1	.9	.9	.9	.9	.7	.7	.7	.4	.2
	VAL	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539
21	% CHI	13.9	10.0	7.4	5.9	4.5	4.3	3.5	2.2	2.0	1.7	1.5	1.5	1.5	1.5	1.3	1.3	1.3	.9	.6	.4
	VAL	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539
22	% CHI	16.0	10.4	8.0	6.3	5.8	4.5	2.6	2.2	1.9	1.5	1.5	1.5	1.5	1.3	1.3	1.3	.9	.6	.4	.4
	VAL	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539
23	% CHI	13.5	16.6	8.7	7.4	5.9	3.9	3.0	2.4	2.0	2.0	2.0	2.0	1.9	1.7	1.5	1.1	.7	.6	.6	.6
	VAL	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	539	538
	TOTAL	21.5	15.8	11.9	9.2	7.1	5.5	4.3	3.4	2.7	2.1	1.7	1.4	1.1	1.0	.8	.7	.5	.4	.3	.3
		13026	13019	13012	13005	12998	12991	12984	12977	12970	12963	12956	12949	12947	12945	12943	12941	12939	12937	12936	12935

CRITERIA H

CUMULATIVE % PROBABILITY OF CONTINUANCE OF CONDITIONS BY MONTH-START HOUR

STATION 40047

MONTH 04

PAGE 3

HOUR		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	GTR
00	% CRI	.4	.4	.2	.2	.2															
	VAL	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939
01	% CRI	.4	.2	.2	.2																
	VAL	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939
02	% CRI	.2	.2	.2																	
	VAL	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939
03	% CRI	.2	.2																		
	VAL	939	939	939	939	939	939	939	939	939	939	939	939	939	939	938	939	939	935	939	938
04	% CRI	.4																			
	VAL	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	938	938
05	% CRI																				
	VAL	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	938	938	938
06	% CRI	.2																			
	VAL	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	938	938	938	938
07	% CRI																				
	VAL	939	939	939	939	939	939	939	939	939	939	939	939	939	939	939	938	938	938	938	938
08	% CRI	.2	.2																		
	VAL	939	939	939	939	939	939	939	939	939	939	939	939	939	939	938	938	938	938	938	938
09	% CRI	.2																			
	VAL	939	939	939	939	939	939	939	939	939	939	939	939	939	938	938	938	938	938	938	938
10	% CRI																				
	VAL	939	939	939	939	939	939	939	939	939	939	939	939	938	938	938	938	939	938	938	938
11	% CRI																				
	VAL	939	939	939	939	939	939	939	939	939	939	939	938	938	938	938	938	938	938	938	938

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CRITERIA M — CUMULATIVE % PROBABILITY OF CONTINUANCE OF CONDITIONS BY MONTH-START HOUR

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HOUR		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	GTR
12	% CRI																				
	VAL	999	999	999	999	999	999	999	999	999	999	998	998	998	998	998	998	998	998	998	998
13	% CRI	.2	.2																		
	VAL	999	999	999	999	999	999	999	999	999	998	998	998	998	998	998	998	998	998	998	998
14	% CRI	.2																			
	VAL	999	999	999	999	999	999	999	999	998	998	998	998	998	998	998	998	998	998	998	998
15	% CRI	.2	.2	.2																	
	VAL	999	999	999	999	999	999	999	998	998	998	998	998	998	998	998	998	998	998	998	998
16	% CRI	.2	.2																		
	VAL	999	999	999	999	999	999	998	998	998	998	998	998	998	998	998	998	998	998	998	998
17	% CRI	.2																			
	VAL	999	999	999	999	999	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998
18	% CRI	.2	.2																		
	VAL	999	999	999	999	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998
19	% CRI	.2																			
	VAL	999	999	999	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998
20	% CRI																				
	VAL	999	999	998	998	998	998	998	998	998	998	998	999	998	998	998	998	998	998	998	998
21	% CRI	.6	.4	.4	.2	.2															
	VAL	999	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998
22	% CRI	.4	.4	.2	.2																
	VAL	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998
23	% CRI	.6	.4	.4	.2	.2	.2														
	VAL	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998	998
	TOTAL %	.2	.1	.1	.0	.0	.0														
	TOTAL	12934	12933	12932	12931	12930	12929	12928	12927	12926	12925	12924	12923	12922	12921	12920	12919	12918	12917	12916	12915

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APPENDIX E

ILLUSTRATION OF CHI-SQUARE GOODNESS-OF-FIT TEST

Appendix E

Illustration of Chi-Square Goodness-of-Fit Test

This appendix illustrates the use of the Chi-Square Goodness-of-Fit Test described in Chapter III. The example is for one of ten weather states tested using data from the month of February. The data are based on 12,192 weather observations for each hour of the day. The results of the tests on the other weather categories follow the example.

Test H_o: The data are distributed geometrically.

H_a: The data are not distributed geometrically.

Reject H_o if $\chi^2 \geq \chi^2_{k-2,1-\alpha}$, where α is the level of significance of the test. (Ref Spiegel: 205)

$$\chi^2 = \sum_{\tau=1}^{k} \frac{(f_\tau - e_\tau)^2}{e_\tau}$$

τ = The number of hours since the initial weather observation.

f_τ = The number of observations in which a real transition from the weather state of interest to another state has occurred.

e_τ = The expected number of real transitions at time τ based on the geometric distribution.

k = The number of classes in the test.

n = The number of observations in the test.

The e_τ were computed from the geometric distribution by $P(T = \tau) \times n = e_\tau$, where

$$P(T = \tau) = pq^{\tau - 1} \qquad \tau = 1, 2, \ldots, k .$$

The parameter q of the geometric distribution was estimated using the maximum likelihood estimator derived in Chapter III.

Appendix E (Continued)

$$\hat{q} = 1 - \frac{n}{\sum_{i=1}^{n} \tau_i}$$

$$= 1 - \frac{774}{1884}$$

$$= 1 - .4108$$

$$= .5892 \; .$$

Therefore, $P(T = \tau) = (.4108)(.5892)^{\tau - 1} \qquad \tau = 1, 2, \ldots, 8$

and $e_\tau = P(T = \tau) \times 774.$

Chi-Square Test for Weather State 9

τ	f_τ	$\tau \times f_\tau = \tau_i$	$P(T = \tau)$	e_τ	$\frac{(f_\tau - e_\tau)^2}{e_\tau}$
1	329	329	.4108	320	0.2531
2	171	342	.2420	189	1.7142
3	109	327	.1425	111	0.0360
4	61	244	.0840	66	0.3787
5	37	185	.0494	39	0.1025
6	36	216	.0291	23	7.3478
7	13	91	.0171	13	0
8	12 }18	96	.0100	8 }13	1.9230
9	6	54	.0059	5	
Totals	$n = 774$	$\sum_{i=1}^{n} \tau_i = 1884$			$\chi^2 = 11.7553$

$$\chi^2_{k-2,\, 1-\alpha} = \chi^2_{6,\ .95} = 12.592 \; ,$$

and $$= \chi^2_{6,\ .99} = 16.812 \; . \qquad \text{(Ref Meyer: 351)}$$

So $\chi^2 = 11.7553 \not\geq \chi^2_{6,\ .95} = 12.592$

$$\not\geq \chi^2_{6,\ .99} = 16.812$$

and H_0 cannot be rejected at $\alpha = .01$ or $\alpha = .05$.

Following are the results of all the Chi-Square tests:

Appendix E (Continued)

Weather State	n	χ^2	Critical Region for $\chi^2_{k-2,\ 1-\alpha}$ $\alpha = .05$	Critical Region for $\chi^2_{k-2,\ 1-\alpha}$ $\alpha = .01$	Results
1	2256	10.645	12.6	16.8	Cannot Reject H_o
2	756	10.985	11.1	15.1	Cannot Reject H_o
3	256	3.949	7.8	11.4	Cannot Reject H_o
4	1146	8.693	7.8	11.4	Reject at $\alpha = .05$ Cannot Reject at $\alpha = .01$
5	683	3.393	9.5	13.3	Cannot Reject H_o
6	232	4.823	7.8	11.4	Cannot Reject H_o
7	1036	35.162	9.5	13.3	Reject H_o
8	2329	3.809	12.6	16.8	Cannot Reject H_o
9	774	11.755	12.6	16.8	Cannot Reject H_o
10	2463	12.585	11.1	15.1	Reject at $\alpha = .05$ Cannot Reject at $\alpha = .01$

APPENDIX F

EXAMPLE OF KOLMOGOROV-SMIRNOV GOODNESS-OF-FIT TEST

Appendix F

Example of Kolmogorov-Smirnov Goodness-of-Fit Test

This appendix illustrates the application of the Kolmogorov-Smirnov (K-S) Goodness-of-Fit Test as described in Chapter III. The K-S test was applied to February data from all ten weather categories. Values for the cumulative distribution $F_T(\tau)$ were computed from the geometric distribution with parameter q estimated as shown in Appendix E. Values for $S_n(\tau)$ were computed from empirical distribution function

$$S_n(\tau) = \begin{cases} 0 & \text{if } \tau < T_{(1)} \\ \frac{k}{n} & \text{if } T_{(k)} \leq \tau < T_{(k+1)} \quad \text{for } k = 1, 2, \ldots, n-1 \\ 1 & \text{if } \tau \geq T_{(n)} \end{cases}$$

where $T_{(1)}, T_{(2)}, \ldots, T_{(n)}$ are the order statistics of the sample and n is the sample size. Gibbons states that the empirical distribution function $S_n(x)$ is "the proportion of sample values that do not exceed the number x." (Ref Gibbons: 73) Siegel, in a similar example of an application of the K-S test, shows that for data which are ordered by time, $S_n(\tau)$ can be expressed as $\frac{f_\tau}{n}$ for $f_\tau = 1, 2, \ldots, n-1$ where f_τ is the number of occurrences corresponding to time τ, and $\frac{f_\tau}{n}$ represents the proportion of sample values that do not occur after time τ. (Ref Siegel: 50) Siegel's format is used in the following examples.

Test H_o : The data are distributed geometrically.

H_a : The data are not distributed geometrically.

Reject H_o if $D_n \geq D_{n,\alpha}$ where $D_n = \sup_\tau |S_n(\tau) - F_T(\tau)|$ and α is the significance level of the test. Critical values for $D_{n,\alpha}$ are tabulated in Reference 4. Following are two examples of how the K-S test was applied:

Appendix F (Continued)

K-S Test for Weather State 1

τ	f_τ	$S_n(\tau)$	$F_T(\tau)$	$\lvert S_n(\tau) - F_T(\tau)\rvert$
1	19	.146	.121	.025
2	11	.231	.226	.005
3	11	.316	.320	.004
4	12	.408	.402	.006
5	12	.500	.474	.026
6	16	.623	.537	.086
7	9	.692	.593	.099
8	10	.769	.642	.127
9	5	.807	.685	.122
10	7	.861	.723	.138
11	0	.861	.756	.105
12	2	.876	.785	.091
13	0	.876	.811	.065
14	2	.891	.833	.058
15	1	.899	.853	.046
16	0	.899	.871	.028
17	0	.899	.886	.013
18	0	.899	.900	.001
19	0	.899	.911	.012
20	0	.899	.922	.022
21	1	.907	.931	.024
22	1	.915	.939	.024
23	1	.923	.946	.023
24	0	.923	.952	.029
25	0	.923	.958	.035
26	1	.930	.962	.032
27	0	.930	.967	.037
28	3	.953	.970	.017
29	2	.968	.974	.006
30	2	.983	.976	.007
31	1	.991	.979	.012
32	0	.991	.981	.010
33	1	.998	.983	.015
34	1	.999	.984	.015
35	0	.999	.986	.013
36	0	.999	.987	.012
37	0	.999	.988	.011
38	0	.999	.989	.010
39	3	1.000	.990	.010

$n = 134$

τ = The number of hours since the initial weather observation at 0600 local time.

f_τ = The number of observations in which a real transition from weather state 1 to another state has occurred.

Appendix F (Continued)

$P(T = \tau) = (.1205)(.8795)^{\tau - 1}$

$D_n = \sup_{\tau} |S_n(\tau) - F_T(\tau)| = .138$

$D_{n,\alpha} = D_{134,\ .01} = .1408$ (Ref 4:426)

Therefore, $D_n = .138 \not\geq D_{134,\ .01} = .1408$ and H_o cannot be rejected at $\alpha = .01$.

K-S Test for Weather State 4

τ	f_τ	$S_n(\tau)$	$F_T(\tau)$	$\lvert S_n(\tau) - F_T(\tau)\rvert$
1	30	.566	.368	.198
2	12	.792	.599	.193
3	5	.886	.746	.140
4	1	.905	.839	.066
5	0	.905	.898	.007
6	0	.905	.936	.031
7	2	.943	.959	.016
8	2	.981	.974	.007
9	0	.981	.984	.003
10	1	1.000	.990	.010

$n = 53$

τ = The number of hours since the initial weather observation at 0600 local time.

f_τ = The number of observations in which a real transition from weather state 4 to another state has occurred.

$P(T = \tau) = (.3666)(.6334)^{\tau - 1}$

$D_n = .198$

$D_{n,\alpha} = D_{53,\ .01} = .2300$ (Ref 4:426)

Therefore, $D_n = .198 \not\geq D_{53,\ .01} = .230$ and H_o cannot be rejected at $\alpha = .01$.

Vita

Dennis Leedom was born [redacted] He was graduated from [redacted] in 1964. He attended the University of Cincinnati where he was elected to both Tau Beta Pi and Sigma Gamma Tau and participated in the cooperative work study program at Aeronautical Systems Division (ASD), Wright-Patterson AFB, Ohio. In 1969, he was graduated with High Honors from the University of Cincinnati with the degree of Bachelor of Science in Aerospace Engineering. During this same year he returned to ASD where he worked as an aerospace engineer in the Advanced Systems Design Division of the Deputy for Development Planning. Later, in 1970, he moved to the Directorate of Advanced Systems Analysis within this same Deputy. He is presently a member of the Operations Research Society of America. He was selected to attend the Graduate Systems Analysis (GSA-73) program starting in September 1971 at the Air Force Institute of Technology, Wright-Patterson AFB, Ohio, where he is working towards the degree of Master of Science in Systems Analysis.

Permanent Address: [redacted]

PII Redacted

PII Redacted

Vita

Arnold R. Thomas, Jr. was born [redacted] He was graduated from [redacted] 1960 and entered the United States Air Force Academy the same year. In 1964 he received a Bachelor of Science Degree and was commissioned in the United States Air Force. Following pilot training, he was assigned as an F-4C pilot at RAF Station, Bentwaters, United Kingdom and was subsequently assigned as an F-4C/D pilot and aircraft commander at Davis-Monthan AFB, Arizona and Danang AB, Vietnam. After flying 215 combat missions in Southeast Asia, Captain Thomas became combat ready in the F-102 and F-106 and was assigned to the 48th Fighter-Interceptor Squadron at Langley AFB, Virginia. In 1971 he was assigned to the Air Force Institute of Technology to study for a Master of Science Degree in Systems Analysis.

PII Redacted

Permanent Address: [redacted]

PII Redacted